BLAST EFFECTS IN NON-FREE-FIELD ENVIRONMENTS

A Sampling of Figures, Tables, and References
Pertinent to the Establishment of Injury Criteria
for Occupants of Structures Exposed to Airblast

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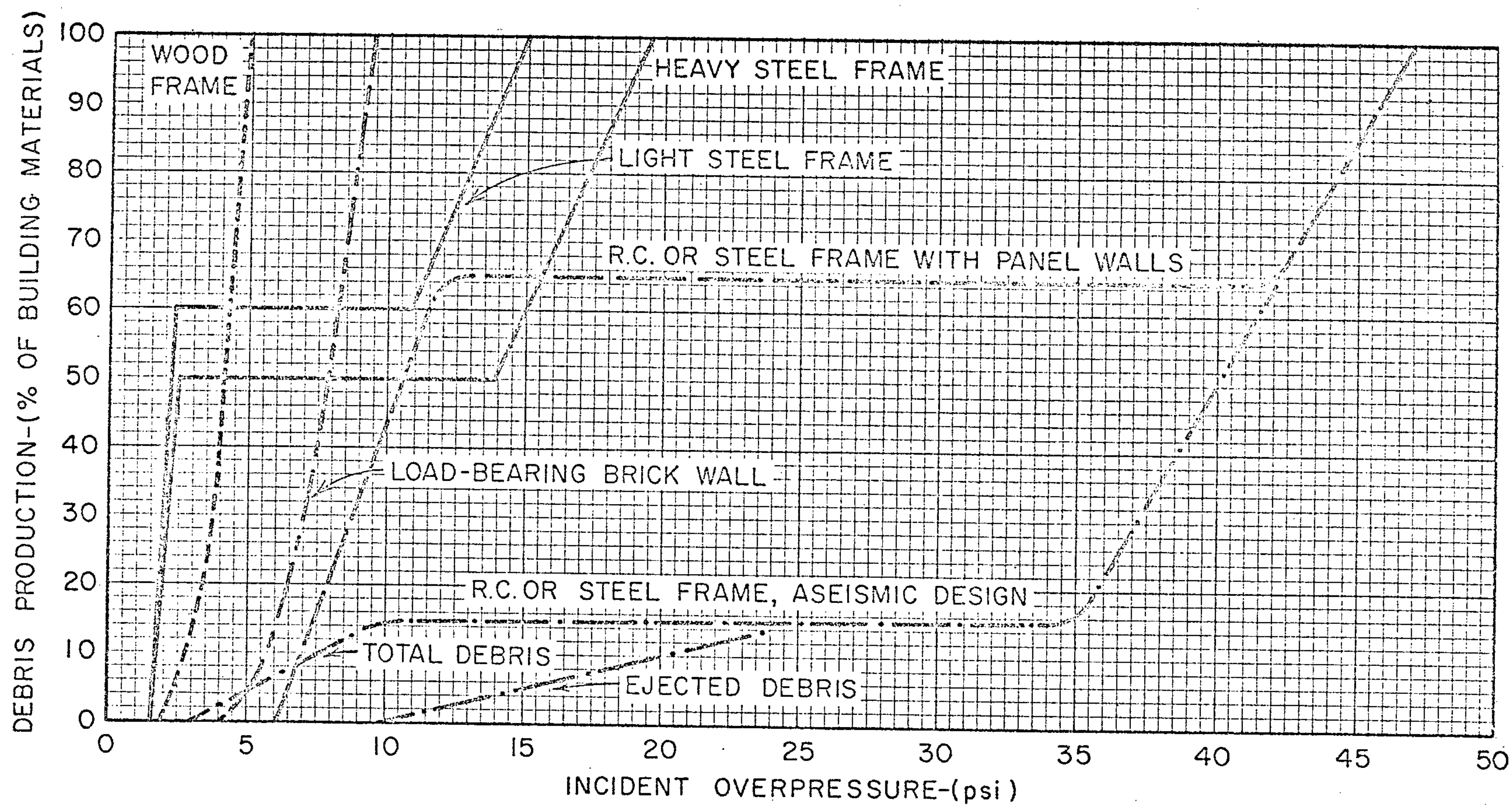
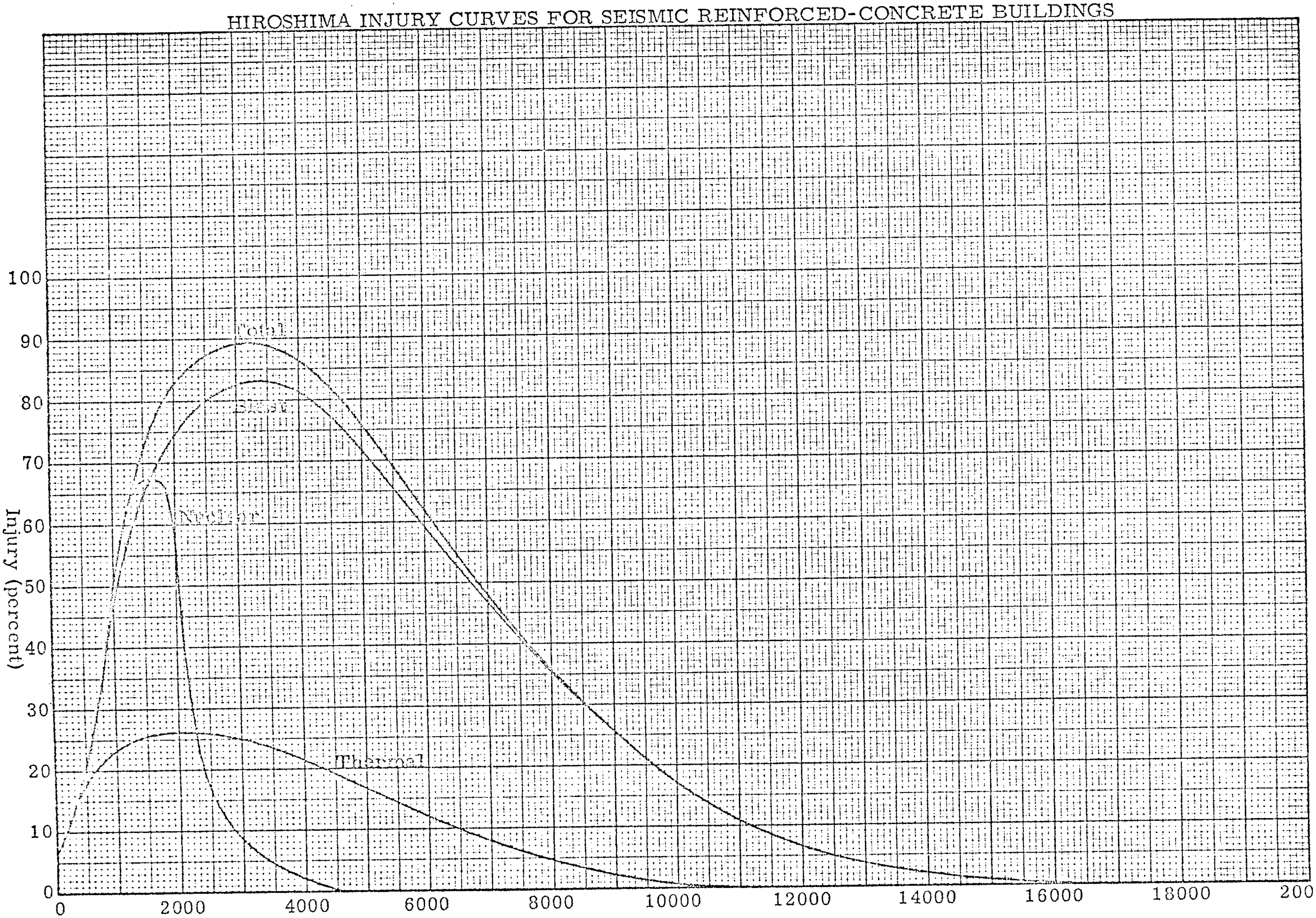


Debris Production vs. Overpressure; 20 Kiloton Weapon

(Figure from Reference 9.)

HIROSHIMA INJURY CURVES FOR SEISMIC REINFORCED-CONCRETE BUILDINGS



(Figure from Reference 8.)

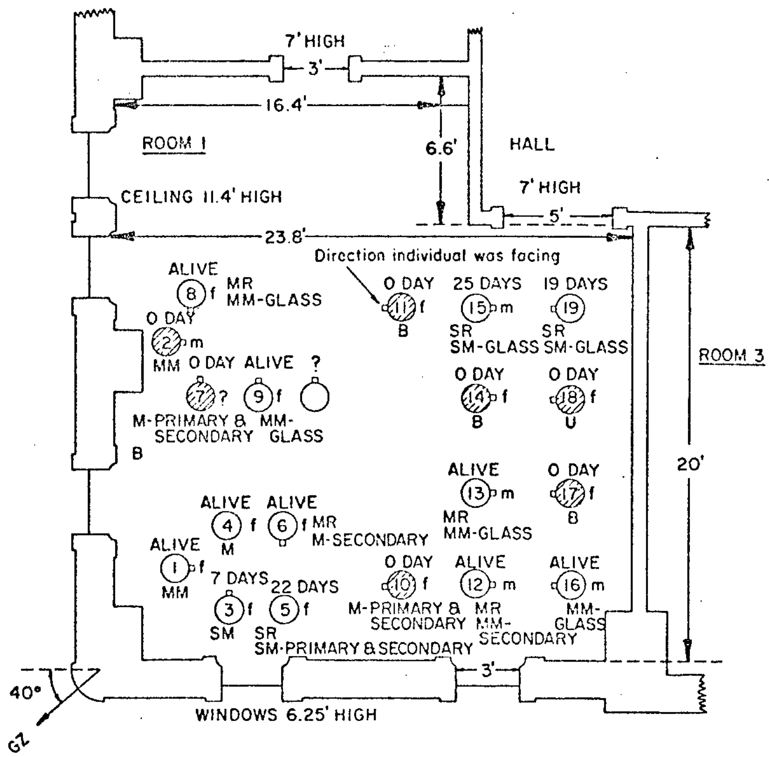
ESTIMATED CASUALTY PRODUCTION IN BUILDINGS

FOR THREE DEGREES OF STRUCTURAL DAMAGE

		Percent of Personnel*		
	Degree of Structural damage	Killed outright	Seriously injured (hospitalization indicated)	Lightly injured (hospitalization not indicated)
1- and 2-story Brick Homes (high-explosive data from England)	Severe	25	20	10
	Moderate	<5	10	5
	Light	0	<5	<5
Reinforced-concrete Buildings (nuclear data from Japan)	Severe	100	0	0
	Moderate	10	15	20
	Light	<5	<5	15

*These percentages do not include the casualties that might result from fires, asphyxiation, and failure to extricate trapped personnel. The numbers represent the estimated percentages of casualties expected at the maximum range at which a specified structural damage occurs.

(Table Modified from Reference 3.)



Bank of Japan, Hiroshima Branch, Room 1, Third Floor (floor 38' above ground)

Range to ground zero: .242 mi. Max. incident overpressure: 17 psi

Nuclear Radiation: 10^4 rads Thermal Radiation: 60 cal/cm^2

Window area/(room vol)$^{\frac{2}{3}}$ = .265 Door area/(room vol)$^{\frac{2}{3}}$ = .158

Survival time indicated. m: male f: female

M: mechanical injury, degree unknown

MM: moderate mechanical injury

SM: severe mechanical injury

B: burns, degree unknown

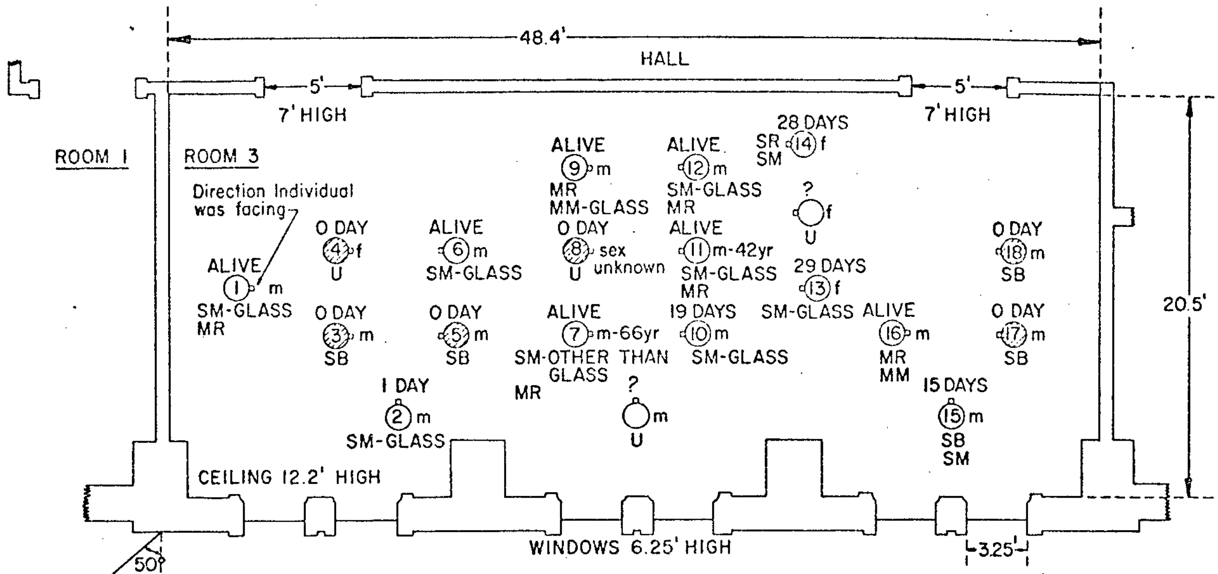
MR: moderate radiation injury

SR: severe radiation injury

U: unknown type of injury

?: unknown fate

(Fate of the Occupants of Room 1, Third Floor of the Hiroshima Branch of the Bank of Japan Figure from Reference 6.)



Bank of Japan, Hiroshima Branch, Room 3, Third Floor (floor 38' above ground)

Range to ground zero: .242 mi. Max. incident overpressure: 17 psi

Nuclear Radiation: 10^4 rads Thermal Radiation: 60 cal/cm^2

Window area/(room vol)$^{\frac{2}{3}}$ = .231 Door area/(room vol)$^{\frac{2}{3}}$ = .133

Survival time indicated. Age at time of burst indicated where known.

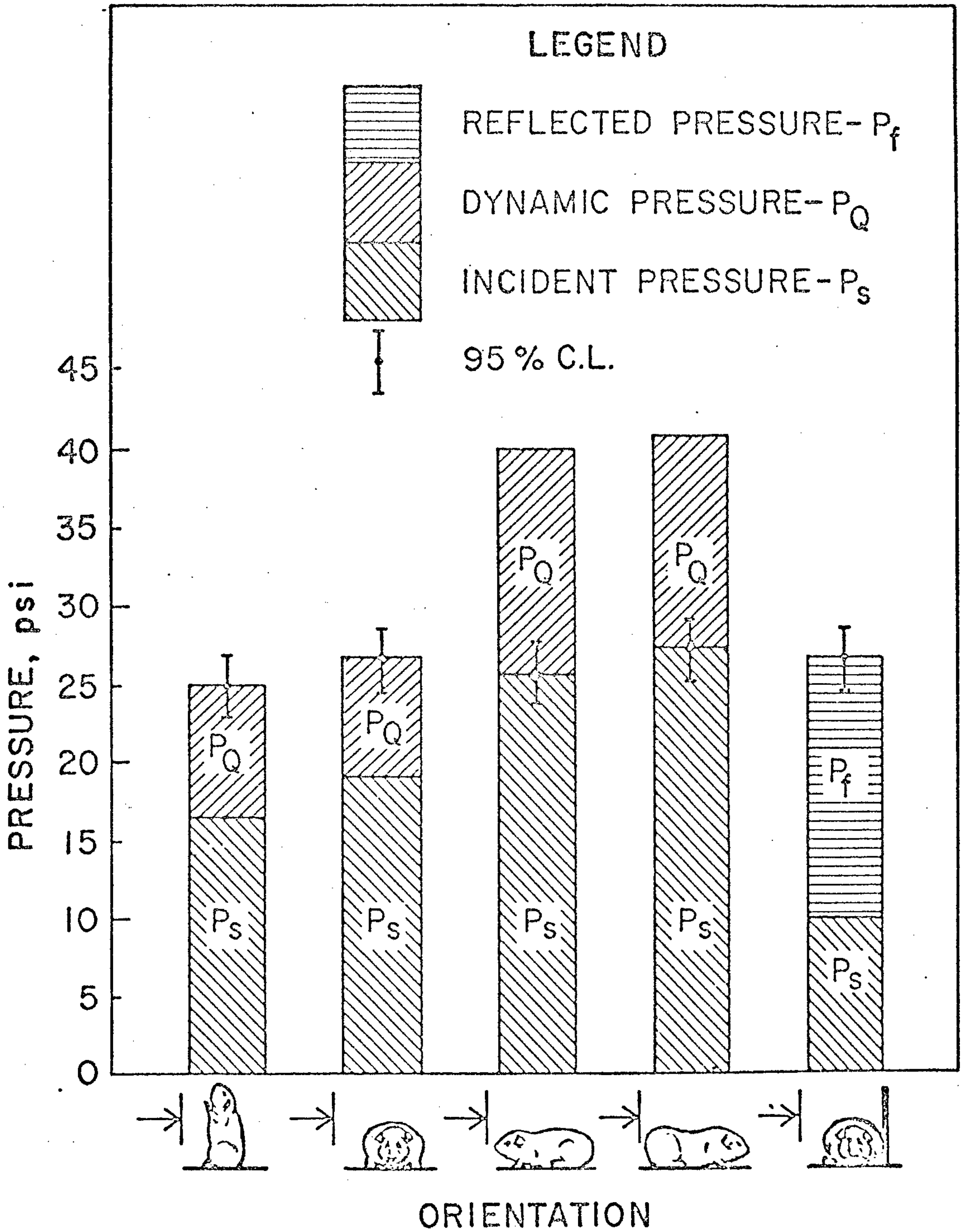
MM: moderate mechanical injury MR: moderate radiation injury

SM: severe mechanical injury SR: severe radiation injury

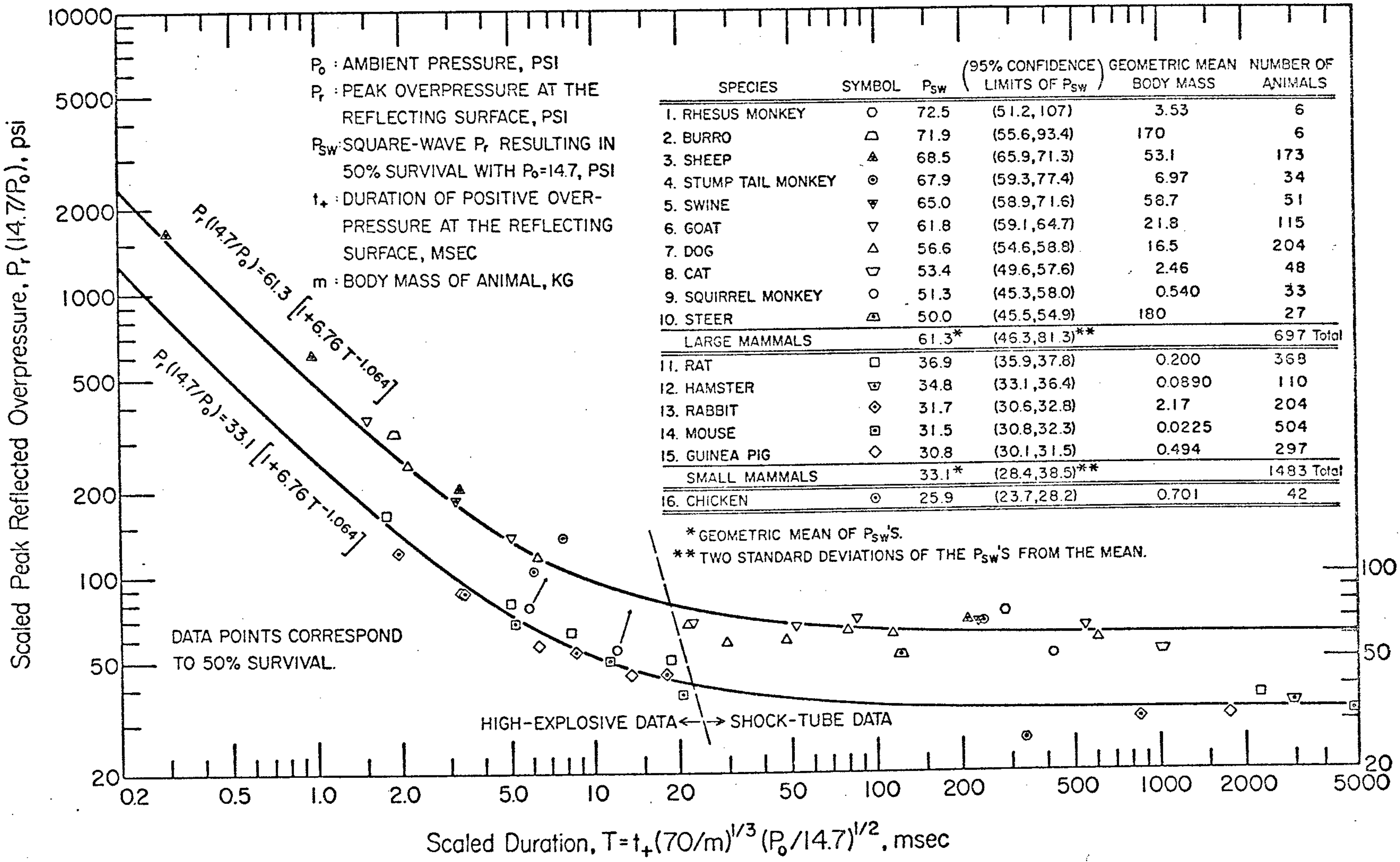
SB: severe burns U: unknown type of injury

?: unknown fate m: male ; f: female

(Fate of the Occupants of Room 3, Third Floor of the Hiroshima Branch of The Bank of Japan Figure from Reference 6.)

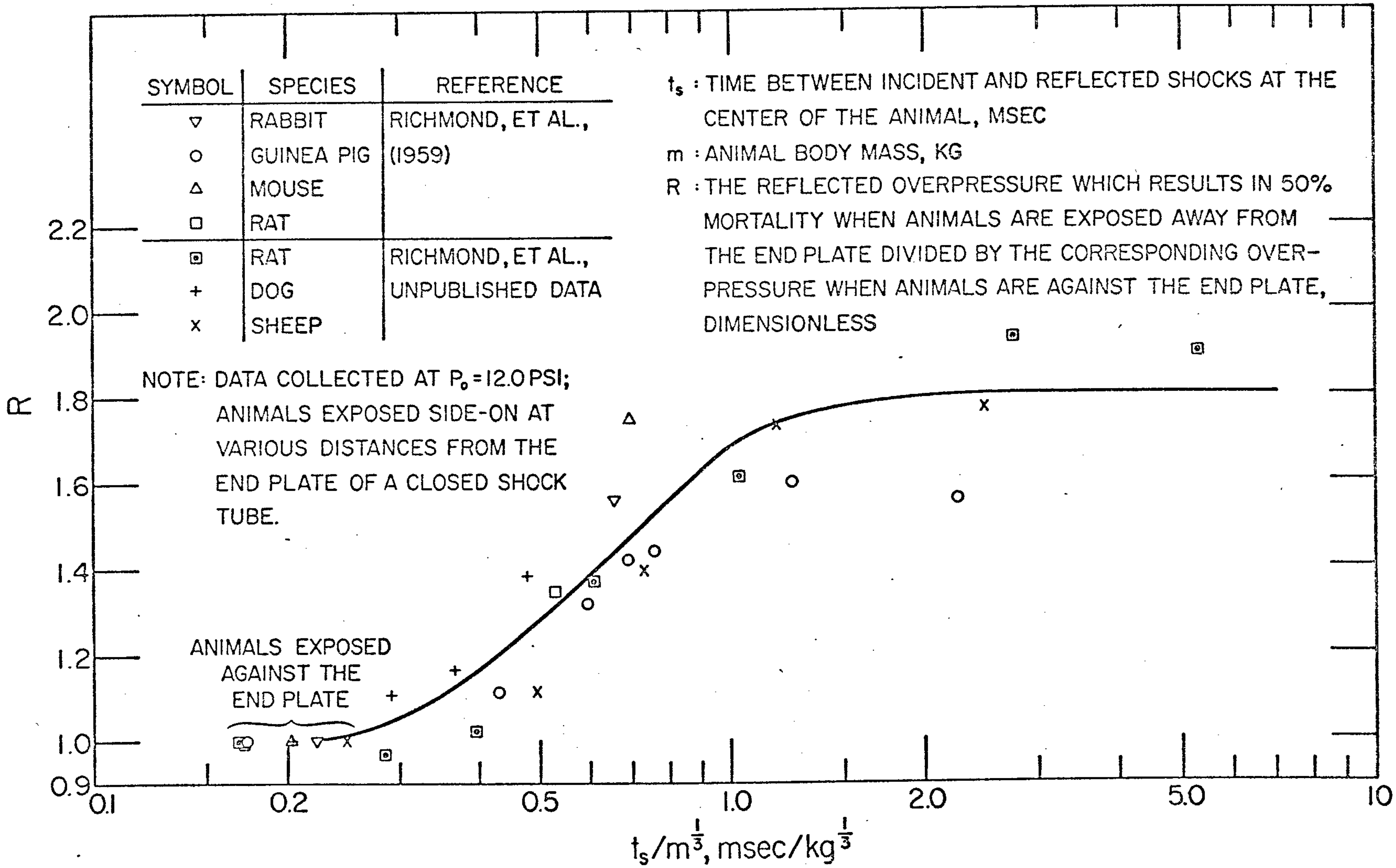


(LD_{50} Conditions for Guinea Pigs in Various Orientations. Measurements Were Made at Ambient Pressure of 12 Psia. Figure from Reference 21.)



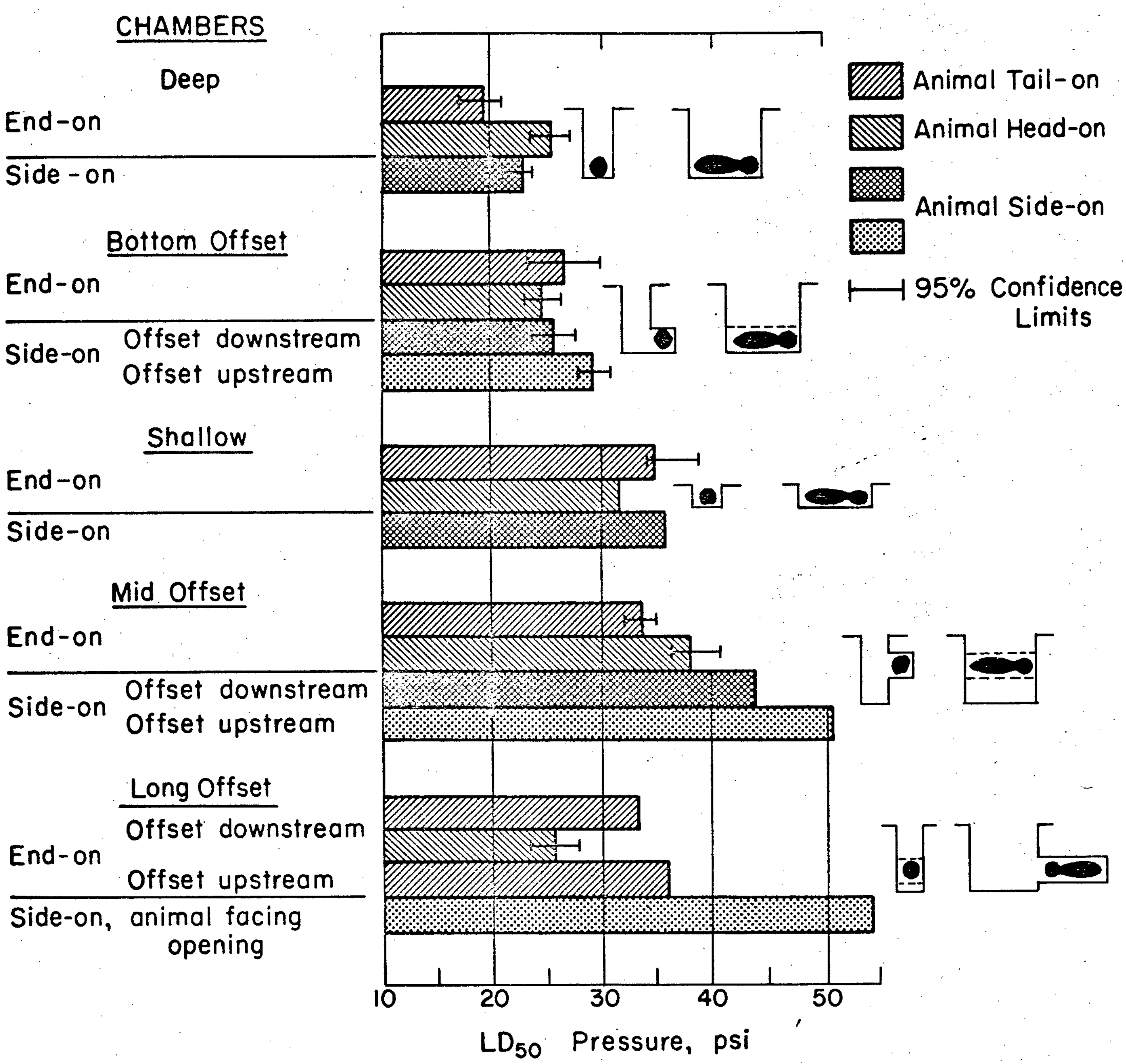
SPECIES	SYMBOL	P_{SW}	(95% CONFIDENCE LIMITS OF P_{SW})	GEOMETRIC MEAN BODY MASS	NUMBER OF ANIMALS
1. RHESUS MONKEY	○	72.5	(51.2, 107)	3.53	6
2. BURRO	⏢	71.9	(55.6,93.4)	170	6
3. SHEEP	▲	68.5	(65.9,71.3)	53.1	173
4. STUMP TAIL MONKEY	⊙	67.9	(59.3,77.4)	6.97	34
5. SWINE	▼	65.0	(58.9,71.6)	58.7	51
6. GOAT	▽	61.8	(59.1,64.7)	21.8	115
7. DOG	△	56.6	(54.6,58.8)	16.5	204
8. CAT	▽	53.4	(49.6,57.6)	2.46	48
9. SQUIRREL MONKEY	○	51.3	(45.3,58.0)	0.540	33
10. STEER	⏢	50.0	(45.5,54.9)	180	27
LARGE MAMMALS		61.3*	(46.3,81.3)**		697 Total
11. RAT	□	36.9	(35.9,37.8)	0.200	368
12. HAMSTER	▽	34.8	(33.1,36.4)	0.0890	110
13. RABBIT	◈	31.7	(30.6,32.8)	2.17	204
14. MOUSE	⊡	31.5	(30.8,32.3)	0.0225	504
15. GUINEA PIG	◇	30.8	(30.1,31.5)	0.494	297
SMALL MAMMALS		33.1*	(28.4,38.5)**		1483 Total
16. CHICKEN	⊙	25.9	(23.7,28.2)	0.701	42

Scaled peak reflected overpressures and scaled durations for sharp-rising blast waves which will result in 50 percent mortality in various species. (Figure from Reference 14.)

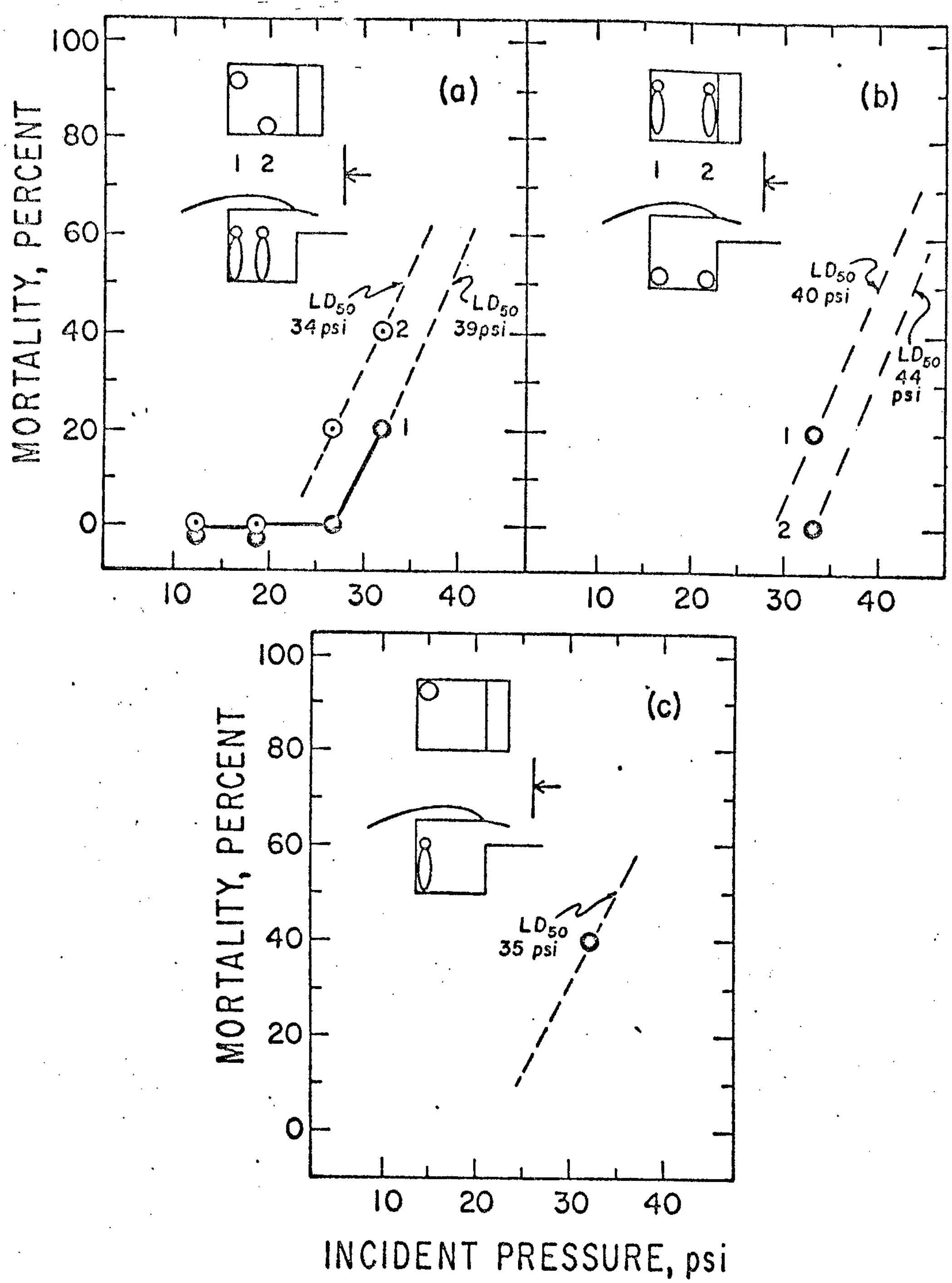


Scaled reflected overpressure which will result in 50 percent mortality when various animals are exposed away from the end-plate of a closed shock tube vs scaled time between the arrivals of the incident and reflected waves. (Figure from Reference 14.)

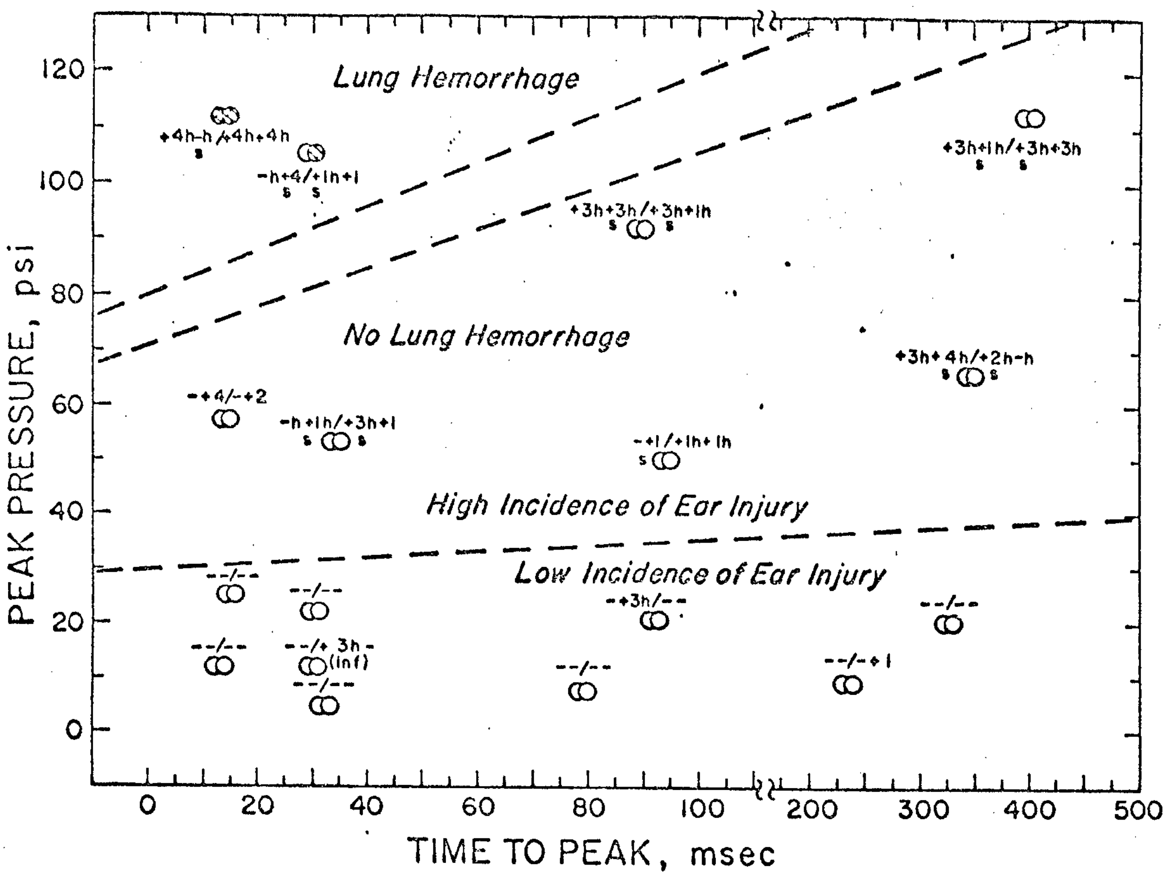
LD_{50} -INCIDENT SHOCK PRESSURE FOR GUINEA PIGS LOCATED IN CHAMBERS ON A SHOCK TUBE



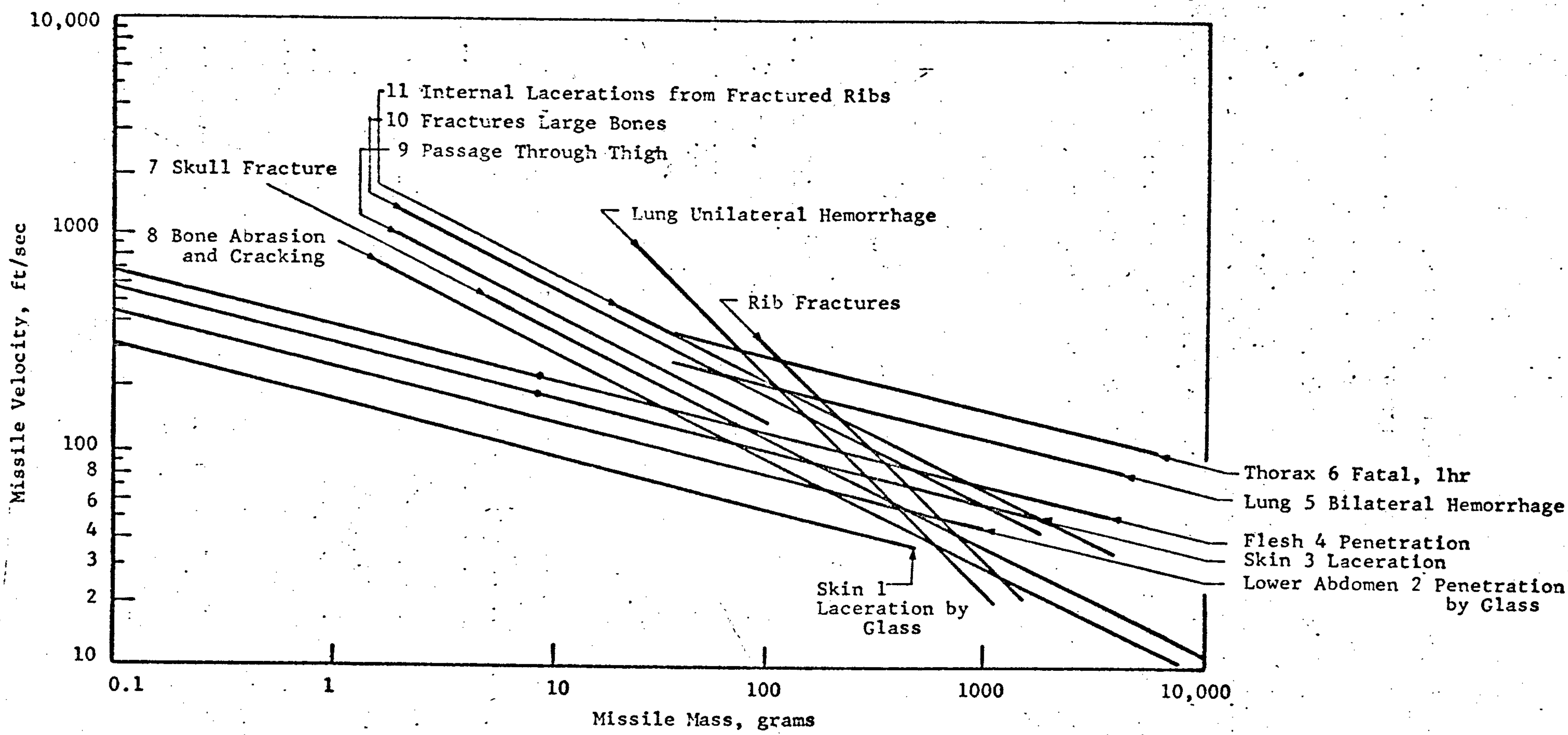
(Figure from Reference 24.)



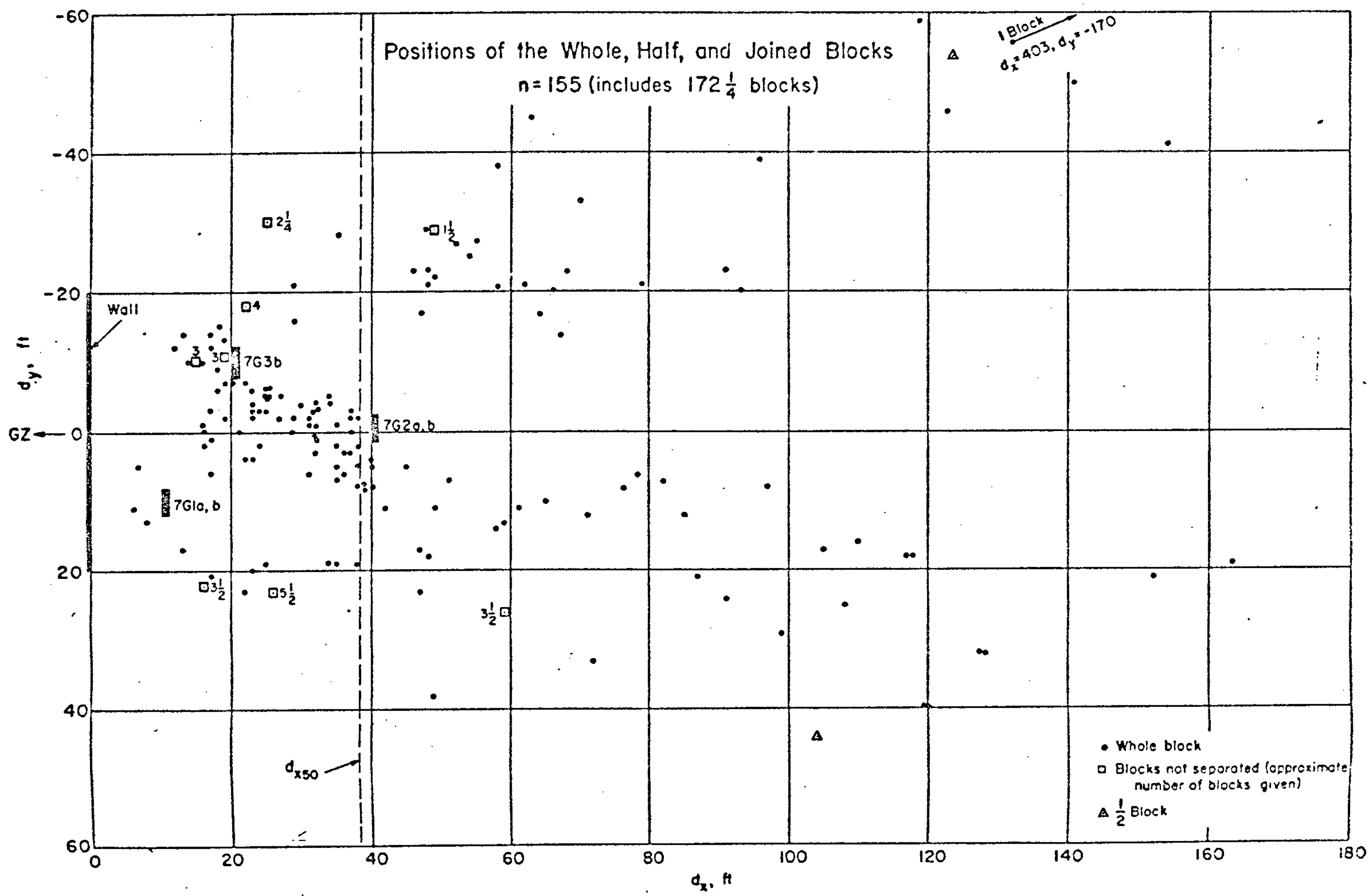
Mortality in Relation to the Incident Shock Pressures for Rats in One-Seventh Scale Models of a 5- x 7-Ft Bunker. (a) Rats vertical near the side and downstream walls; (b) Rats prone at the upstream and downstream walls; (c) Rats vertical in corner. (Figure From Reference 23.)



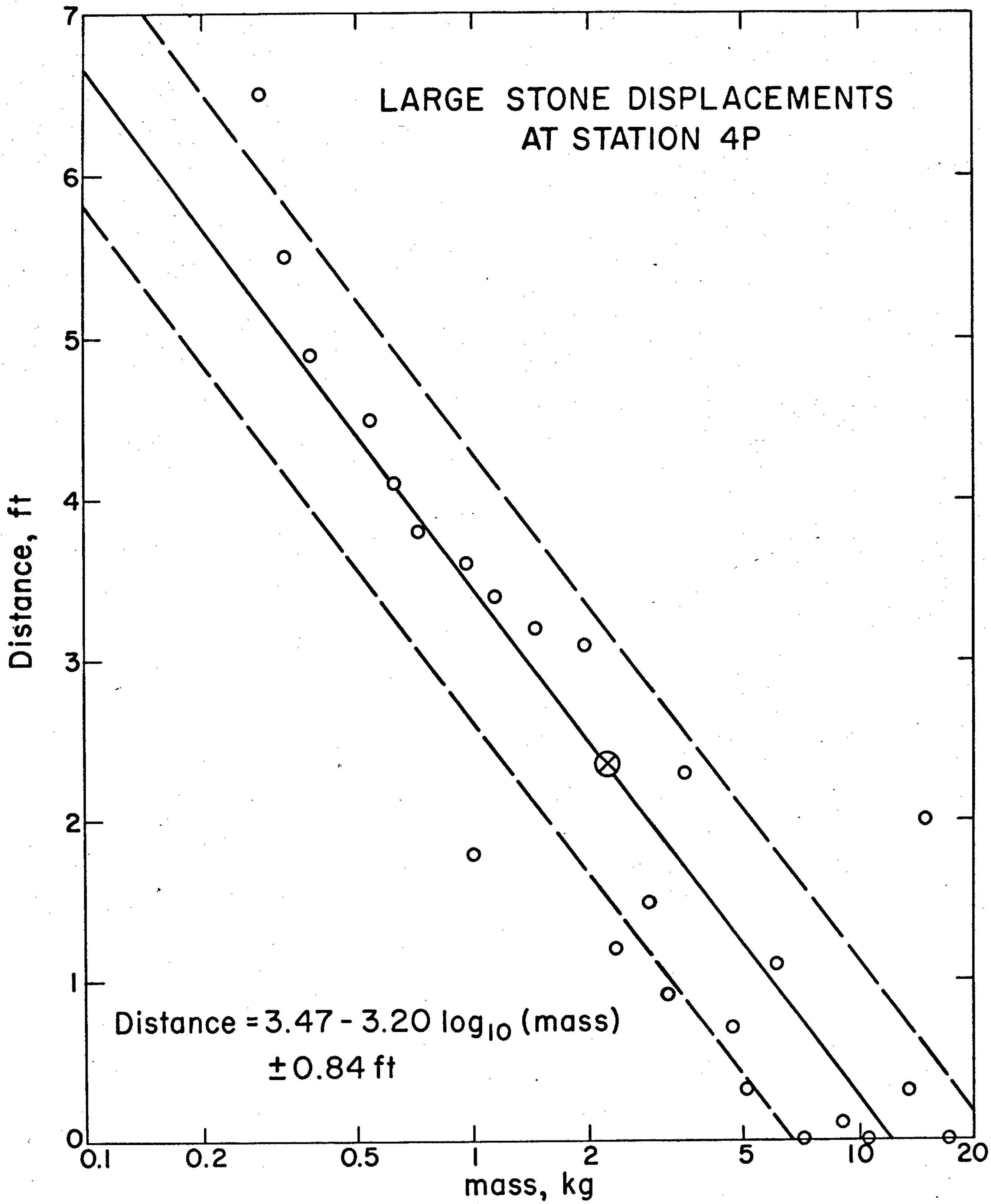
Distribution of Blast Injuries in Dogs in Relation to Peak Pressure and Time To Peak Pressure. ⊗ , lung hemorrhage; s, sinus hemorrhage; other "-" or "+" symbols are for degrees of ear injury as follows: "-" indicates eardrums intact; "h" indicates hemorrhage. "+1," "+2," and "+3" indicate eardrums less than 25% destroyed, between 25 and 50%, and greater than 50% destroyed, respectively. "+4" indicates greater than 50% destroyed with malleus fractured or disrupted. (Figure from Reference 22.)



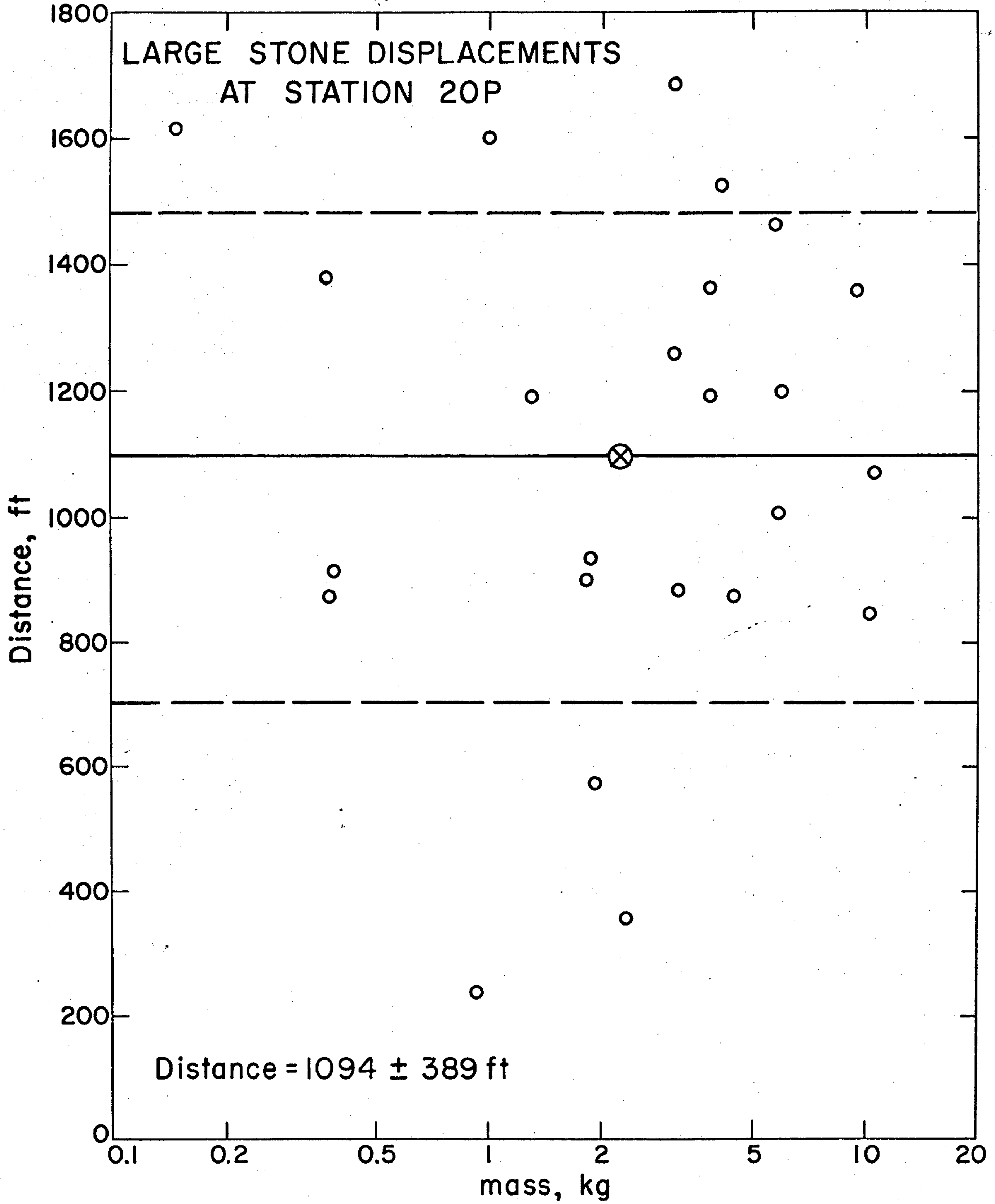
VARIOUS BIOLOGICAL EFFECTS OF MISSILES
(Figure from Reference 10.)



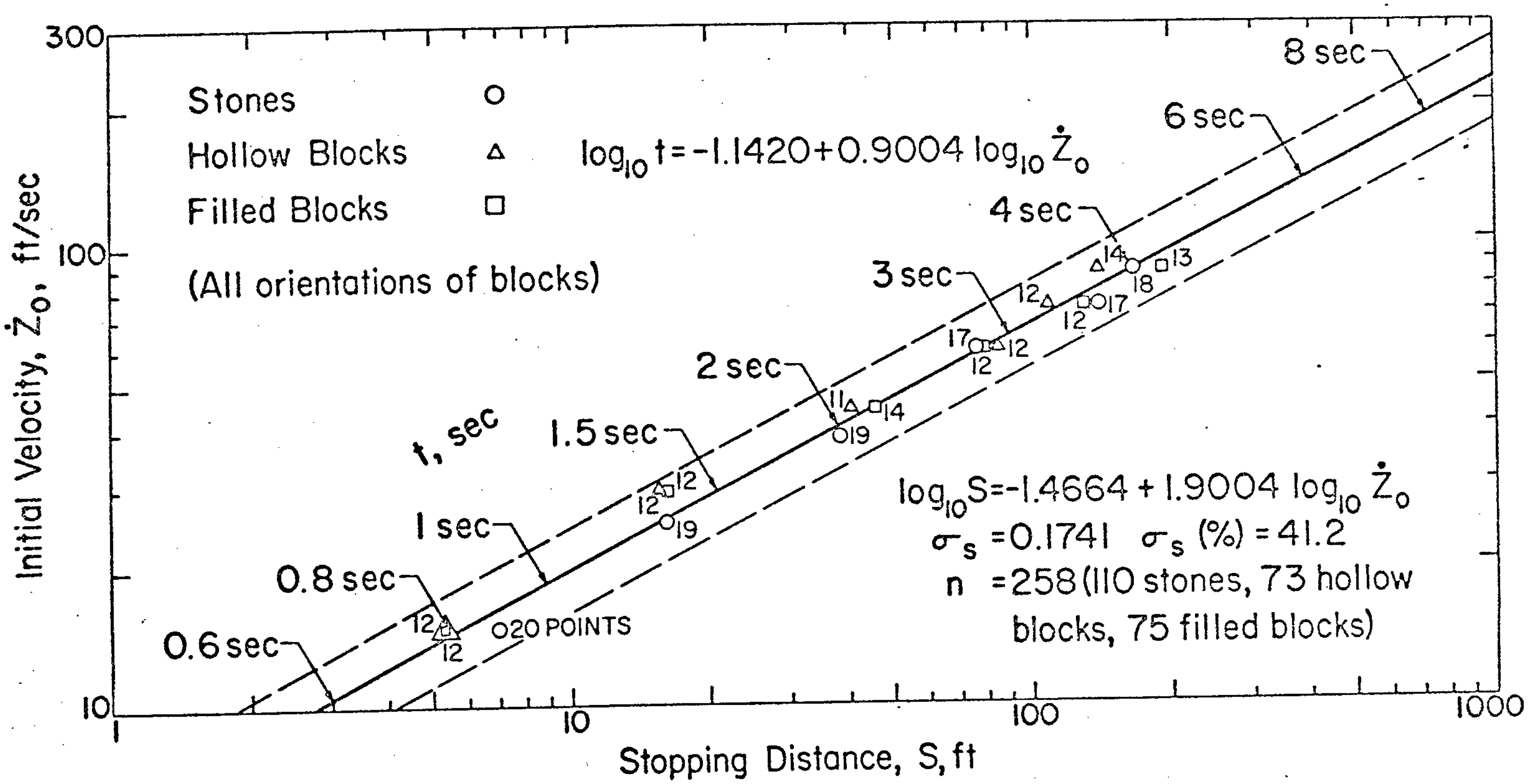
(Spatial distribution of the larger fragments [whole, half, and joined blocks] from a wall exposed to a blast wave with a peak overpressure of 8.7 psi and a duration of 580 msec. Figure from Reference 12.)



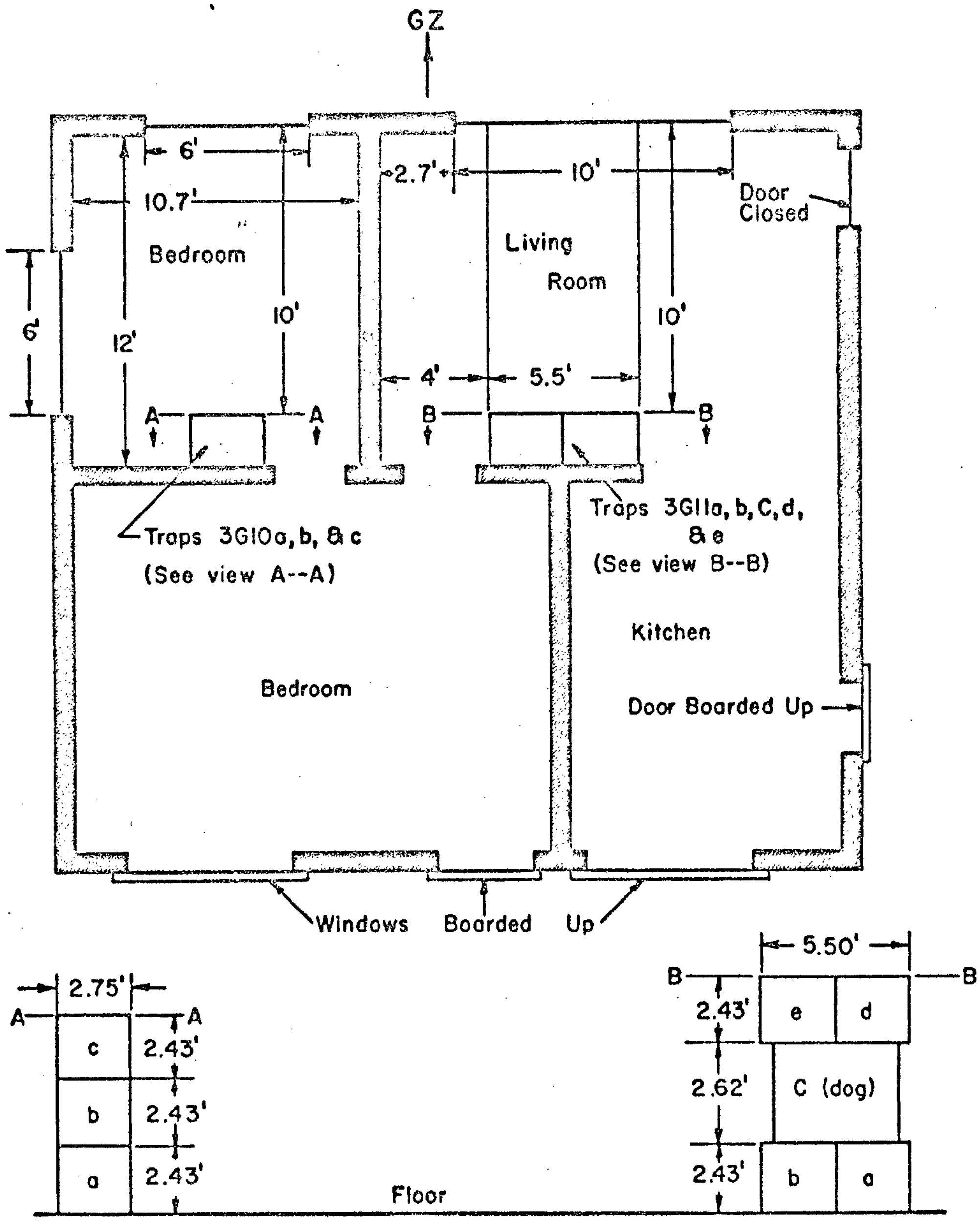
(Displacements of large stones exposed to a near-classical blast wave with a peak overpressure of 4.5 psi and a duration of 1030 msec. Data from Reference 5.)



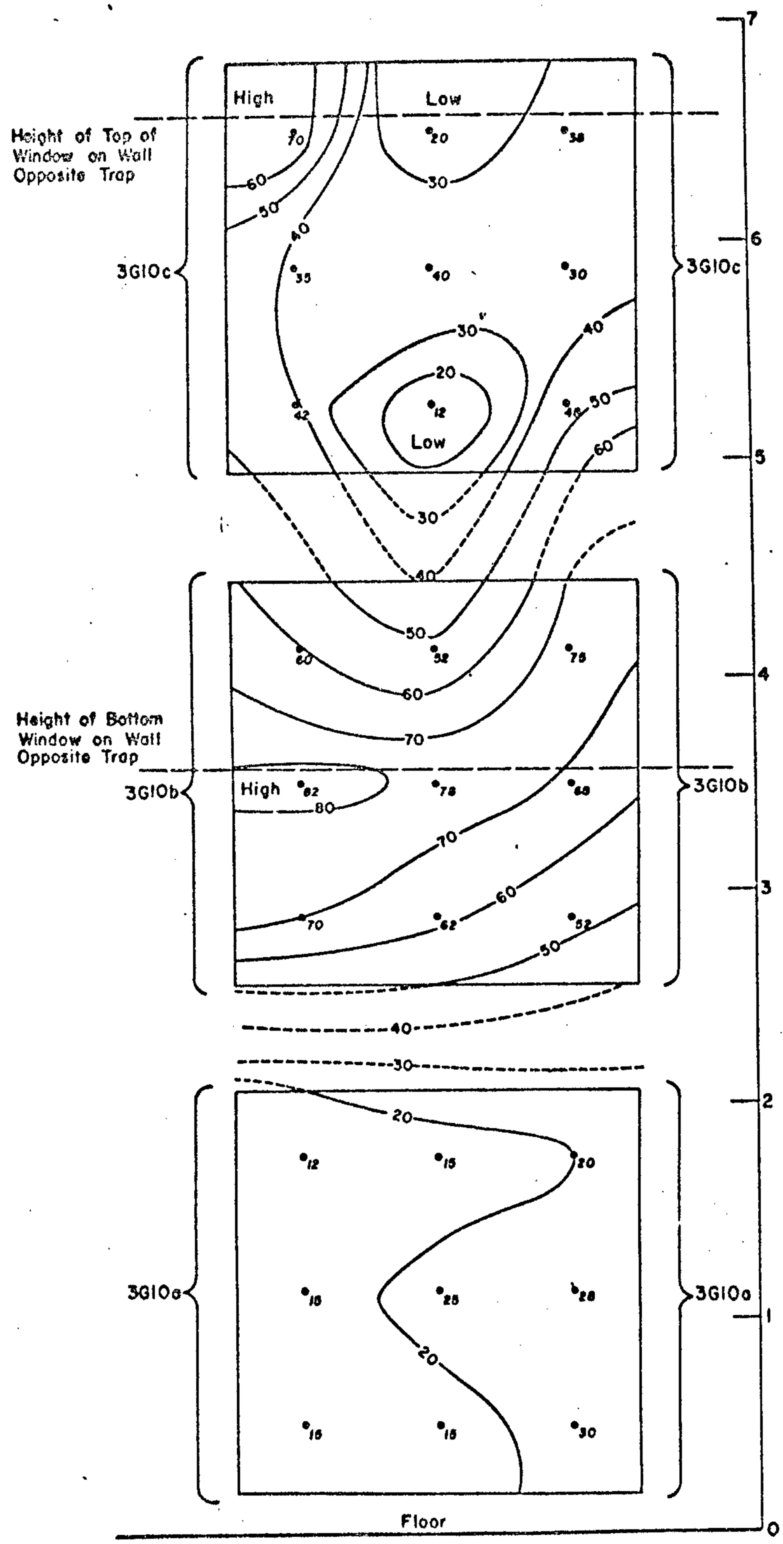
(Displacements of large stones exposed to a precursor-type blast wave with a peak overpressure of 15 psi and a duration of 610 msec. Data from Reference 5.)



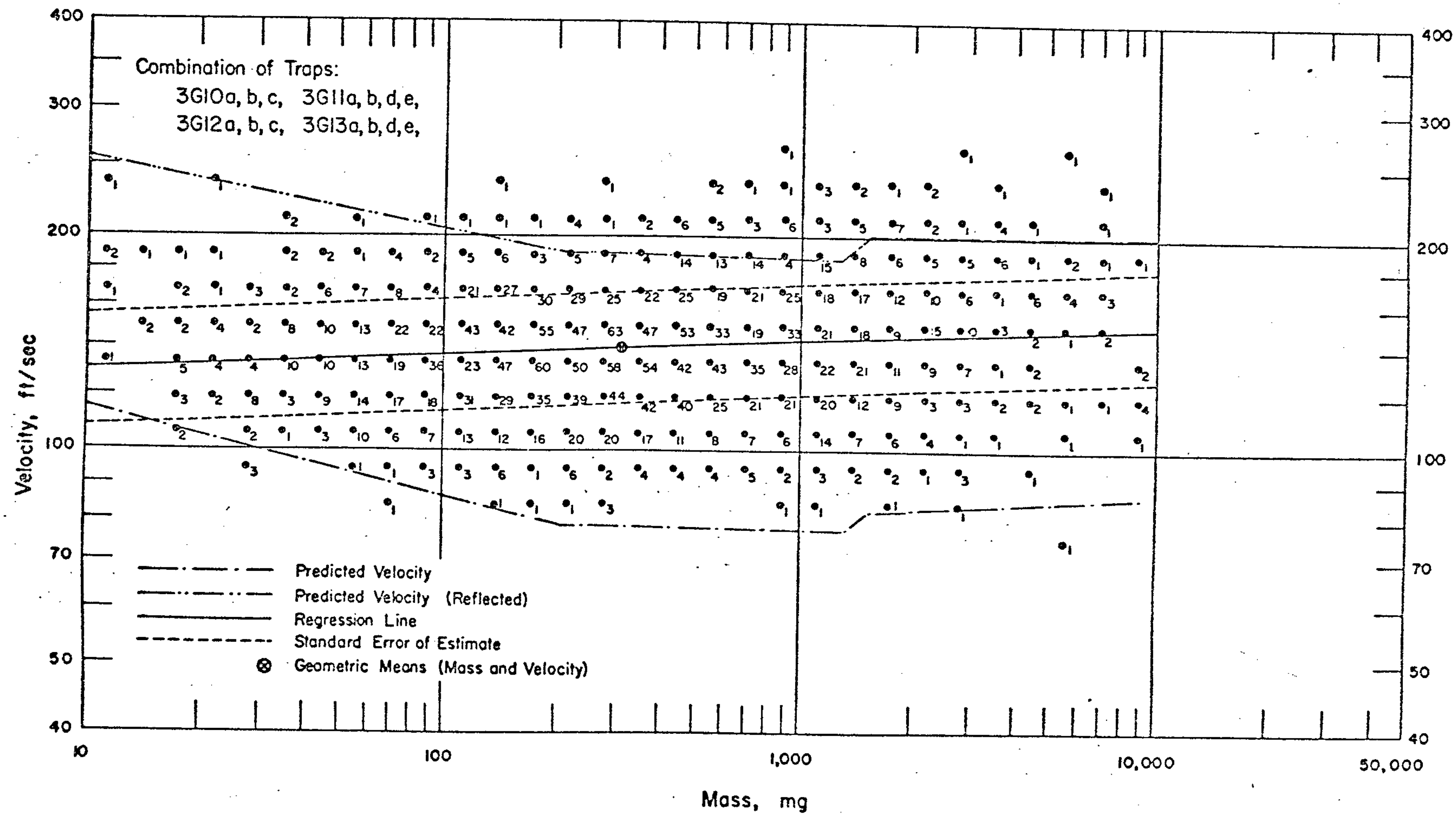
Initial velocity ($\dot{Z}_o$) vs displacement (S) for stones, hollow concrete blocks, and filled concrete blocks. Computed stopping times (t) are also indicated. Dashed lines are drawn one standard error of estimate from the regression line. (Figure from Reference 12.)



Floor plan of reinforced concrete-block house, 4700-ft range. Traps 3G10a, b and c, and 3G11a, b, d and e all have type I absorbers. The bedroom window opposite traps 3G10a, b and c is 3 ft 7 in. above the floor, has nine 11.5- by 23.5-in. panes, and is 6 by 3 ft. The living-room window opposite traps 3G11a, b, d and e is 2 ft 7 in. above the floor, has twenty 11.5- by 23.5-in. panes, and is 10 by 4 ft. (Figure from Reference 5.)



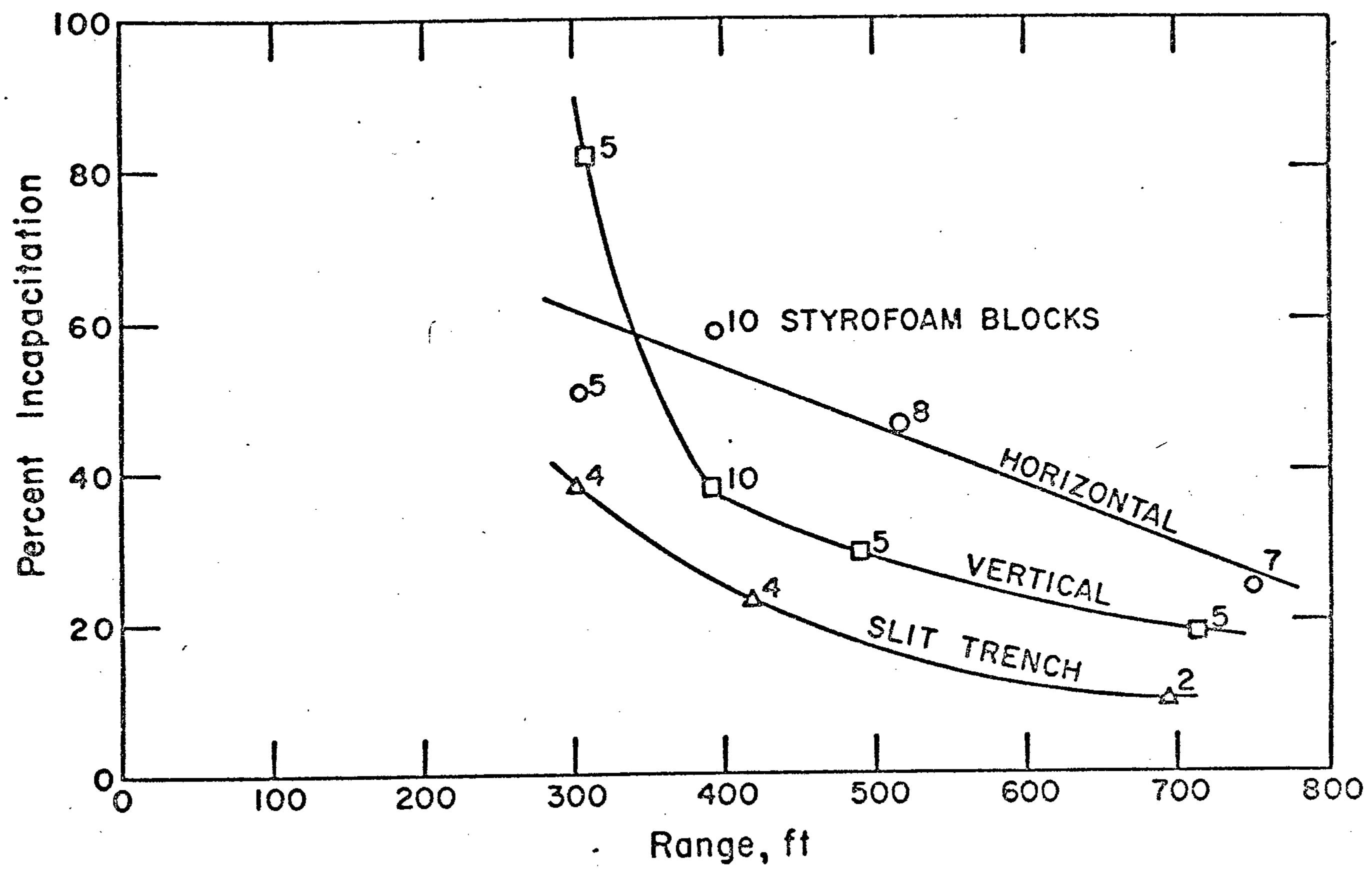
Spatial distribution of window-glass missiles in installation 3G10 traps. Numbers indicate missiles per square foot. (Figure from Reference 5.)



Analysis of window-glass missiles from 14 traps (stations 3G10, 3G11, 3G12, and 3G13): d (average) = 10.3 ft; n = 2523; $\log v = 2.0913 + 0.0216 \log m$; $E_{gv} = 1.20$; $M_{50} = 321$ mg; $V_{50} = 140$ ft/sec.

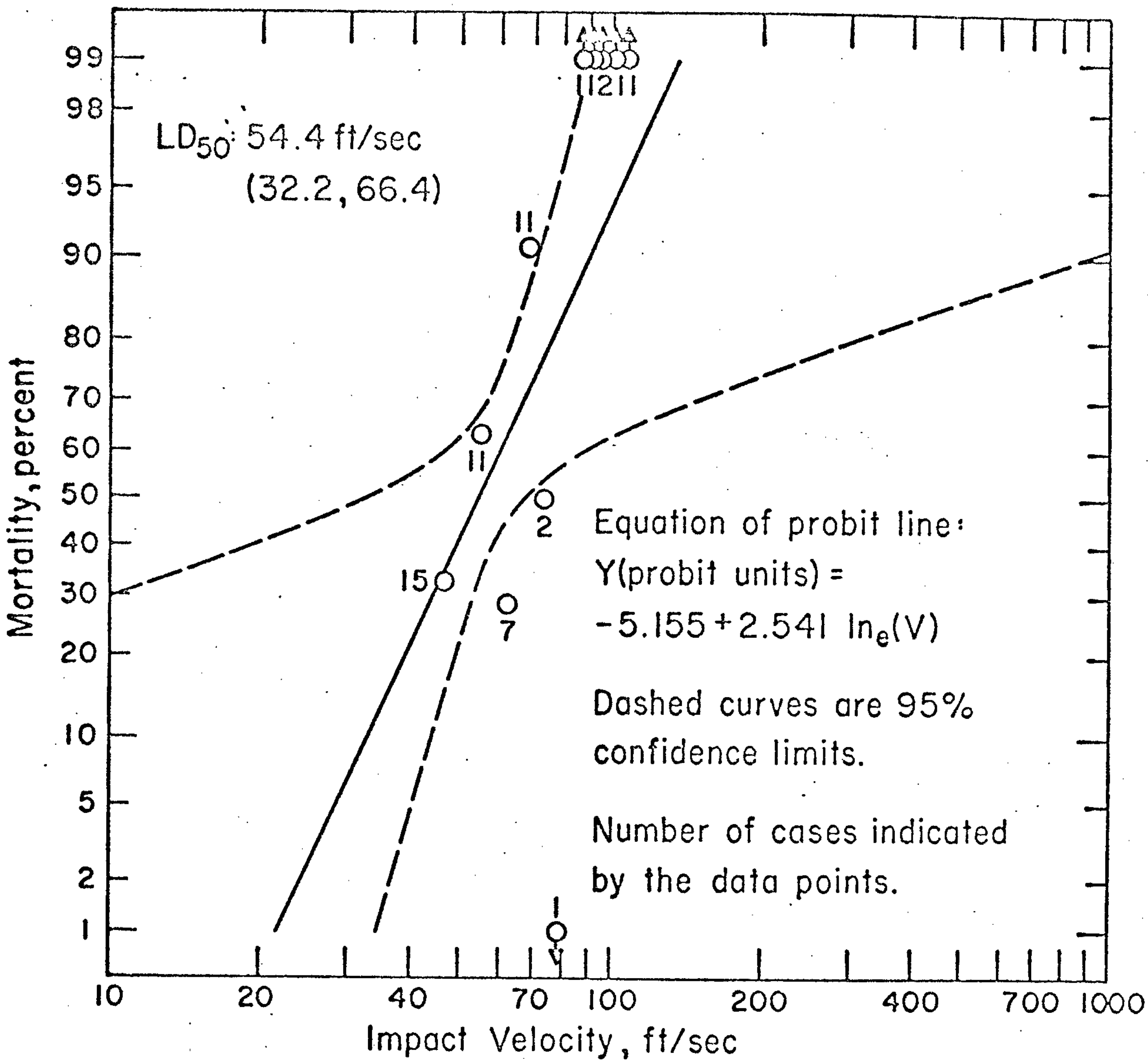
(Figure from Reference 5; predictions computed from material in Reference 4.)

COMPUTED PERCENT INCAPACITATION VS RANGE
FOR THREE TYPES OF EXPOSURE



(Computed percent incapacitation of personnel exposed to a 50-ton HE surface burst in a coniferous forest. Incapacitation is shown as a function of range for personnel [1] standing on the surface [2] prone on the surface or [3] prone in a slit trench. Figure from Reference 13.)

53 Human Free-Fall Cases from Lewis et al., 1965
(Impact with concrete)



(Figure from Reference 18.)

RESULTS OF PROBIT ANALYSIS RUN ON IMPACT DATA

	Species (Number dying/ number exposed)	Mean Body Mass, kg	Impact Velocities in ft/sec Resulting in 1, 50 and 99% Mortality (with 95% confidence limits)		
			V_1	V_{50}	V_{99}
Perpendicular Impact with a Non-Yielding Surface	Mouse (44/113)	0.0198	30.0 (28.1, 31.5)	39.1 (37.8, 40.4)	50.9 (48.4, 54.5)
	Rat (90/178)	0.185	33.4 (31.2, 35.1)	43.6 (42.4, 44.7)	56.8 (54.4, 60.2)
	Guinea Pig (57/111)	0.650	23.7 (22.2, 24.9)	30.9 (30.0, 31.9)	40.3 (38.4, 43.0)
	Rabbit (26/53)	2.43	24.3 (22.6, 25.8)	31.7 (30.4, 33.2)	41.4 (39.1, 44.6)
	Dog (5/29)	17.6	25.4 (7.16, 34.5)	64.3 (50.0, 146)	163 (94.3, 2280)
	Man (31/53)	~50	21.5 (2.73, 32.7)	54.4 (40.9, 64.2)	138 (95.6, 811)
Decelerative Tumbling over the Ground	Goat (5/19)	36.7	31.7 (7.42, 44.7)	80.4 (62.0, 158)	203 (121, 2380)
	Dog (0/2)	22		$\gtrsim$88	
	Sheep (0/4)	52		$\gtrsim$88	

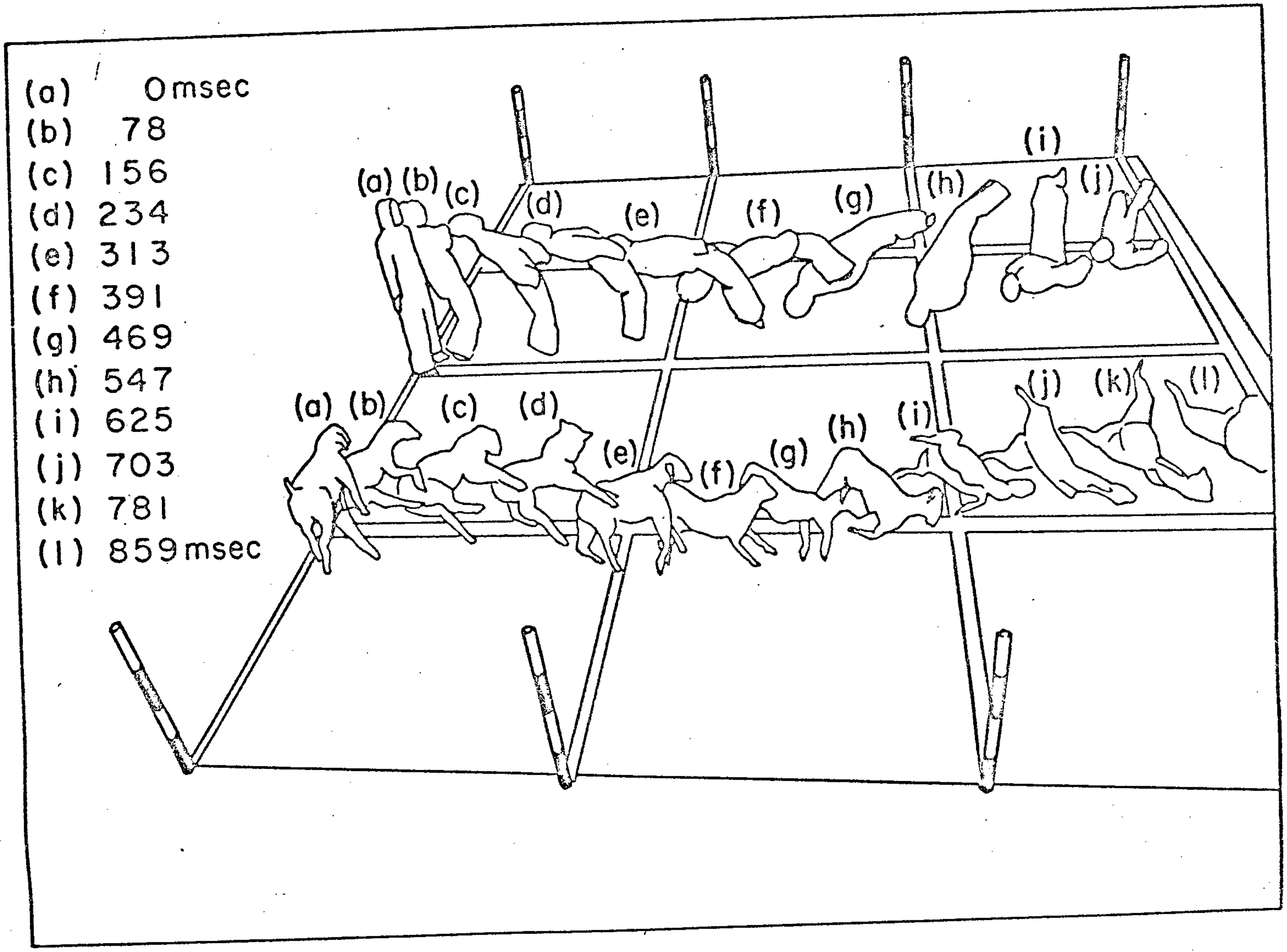
(Table Modified from Reference 18.)

TENTATIVE CRITERIA FOR INDIRECT (TERTIARY)

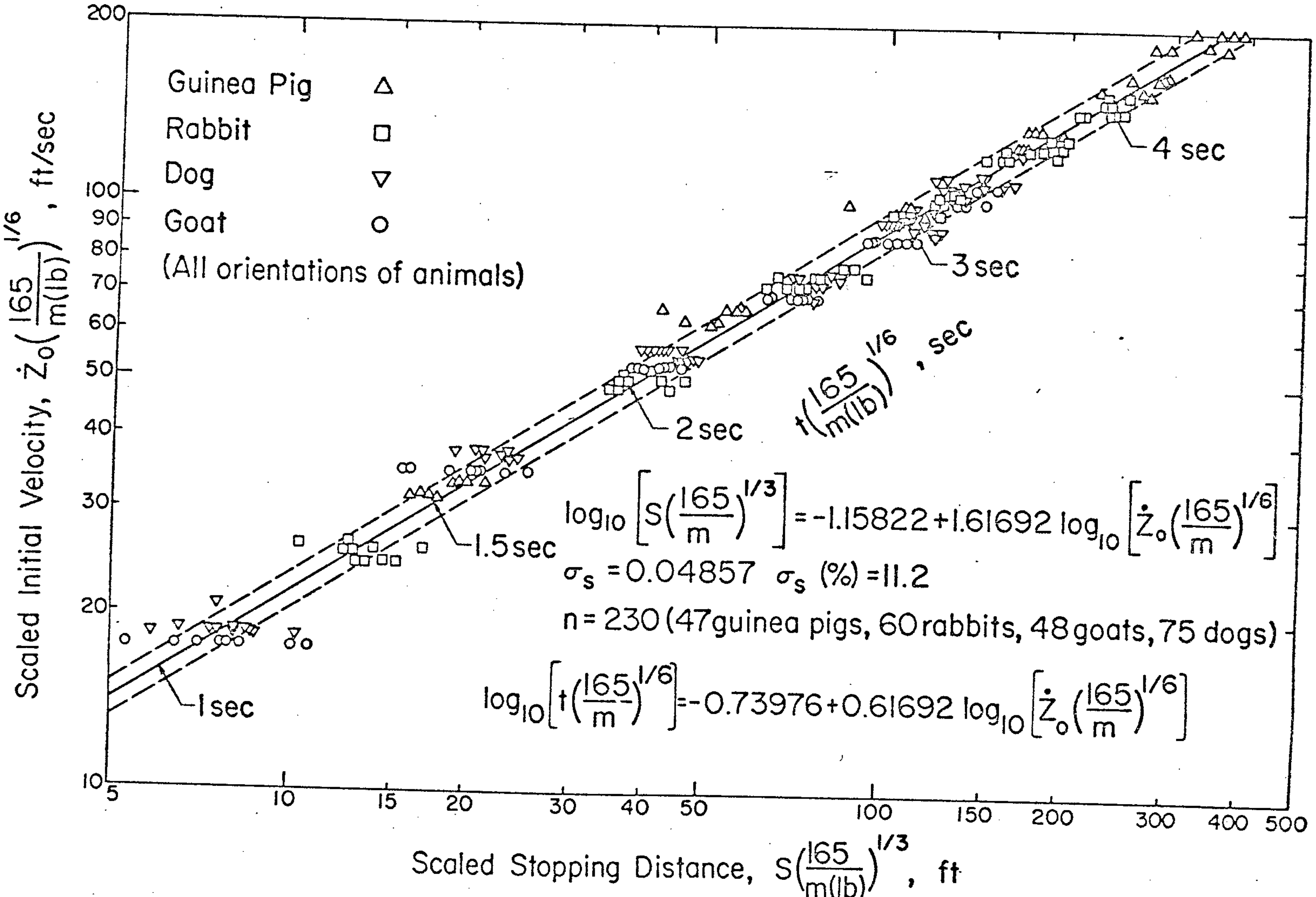
BLAST EFFECTS INVOLVING IMPACT

Condition, Critical Organ, or Event	Related Impact Velocity, ft/sec
Standing Stiff-Legged Impact	
Mostly "safe"	
No significant effect	<8 (?)
Severe discomfort	8 - 10
Injury	
Threshold	10 - 12
Fracture threshold (heels, feet and legs)	13 - 16
Seated Impact	
Mostly "safe"	
No effect	<8 (?)
Severe discomfort	8 - 14
Injury	
Threshold	15 - 26
Skull Fracture	
Mostly "safe"	10
Threshold	13
50 per cent	18
Near 100 per cent	23
Total Body Impact	
Mostly "safe"	10
Lethality threshold	21
Lethality 50 per cent	54
Lethality near 100 per cent	140

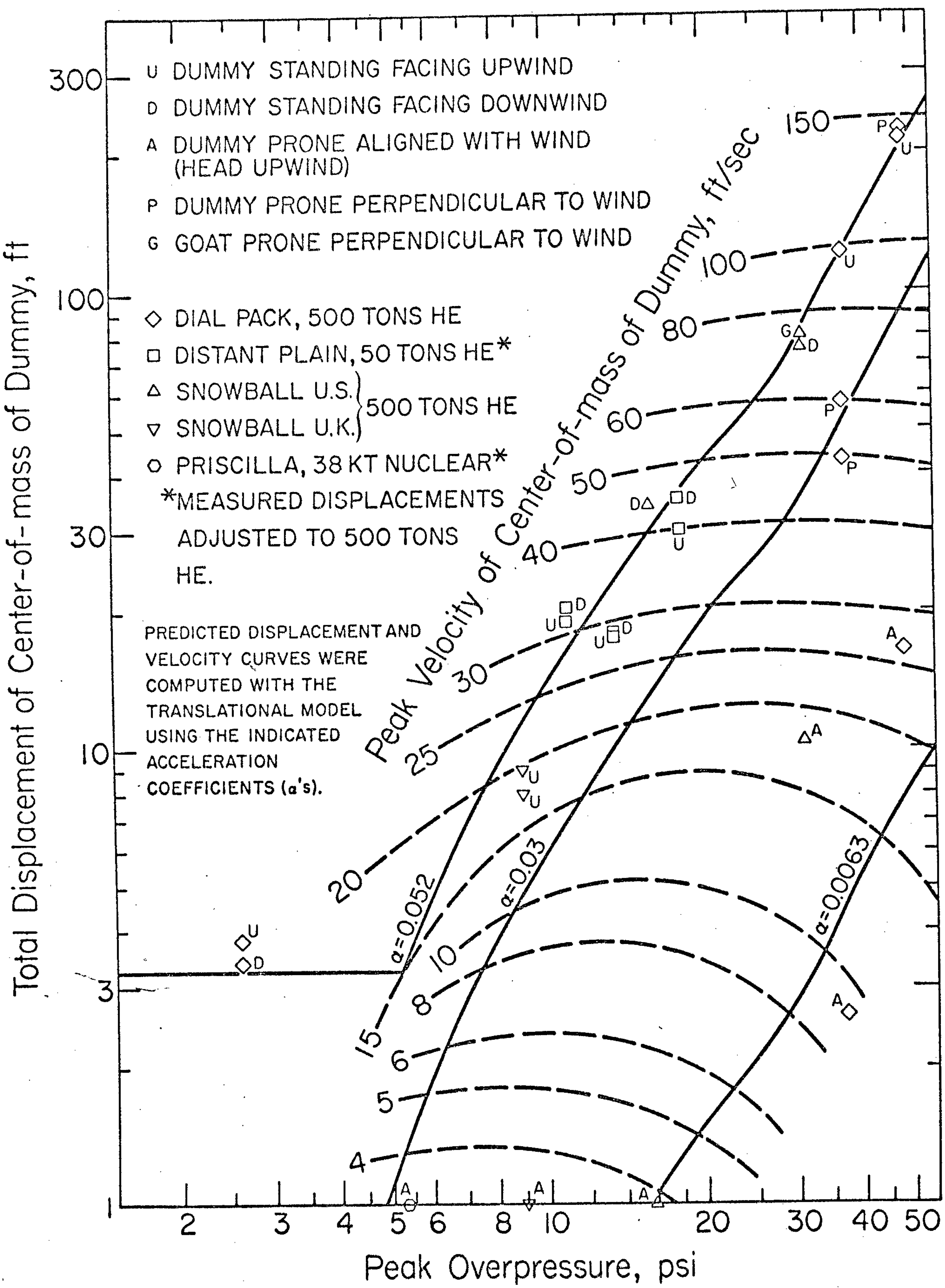
(Table Modified from Reference 25.)



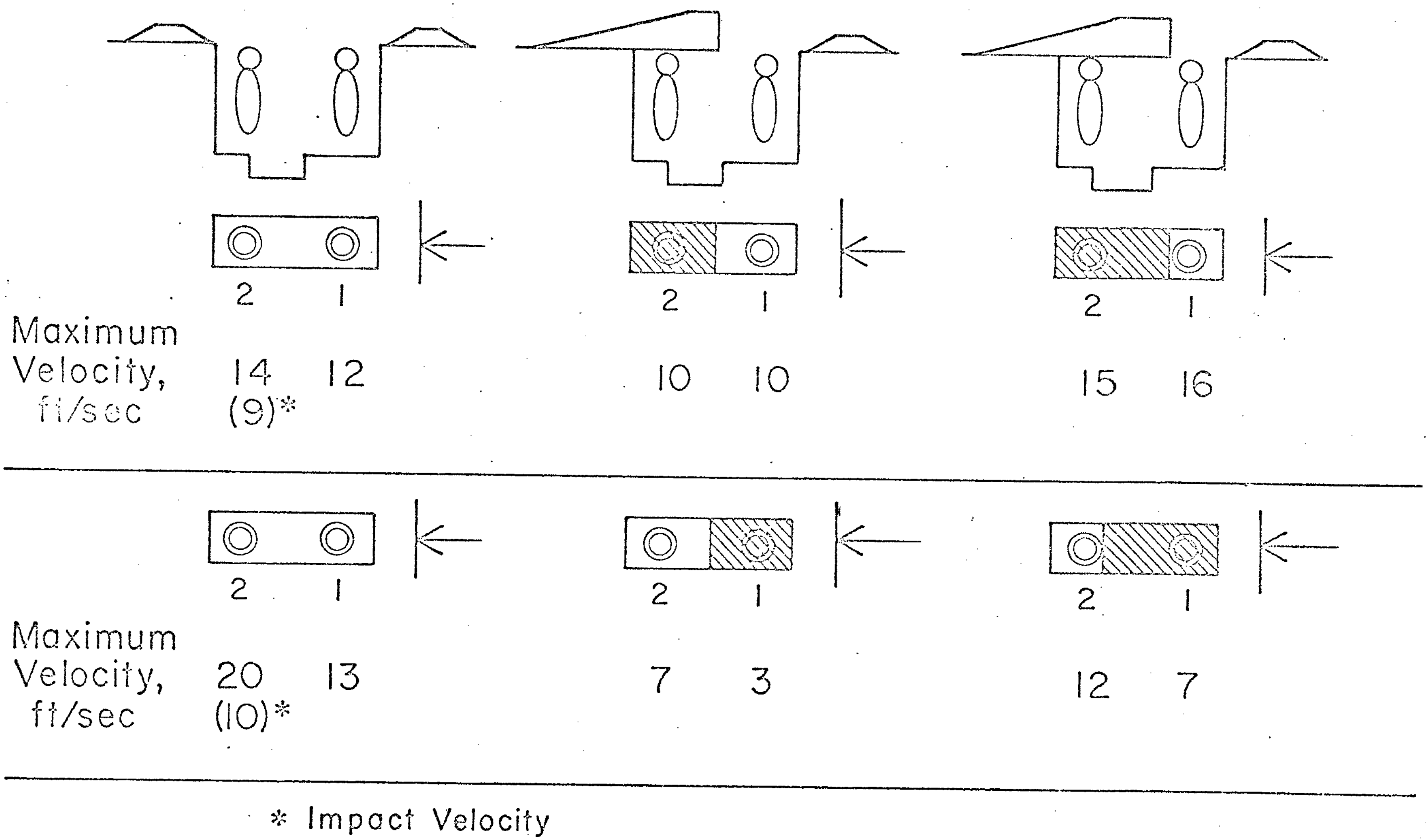
(Composite drawing showing the positions of an initially-standing dummy and goat at the indicated times after the arrival of a blast wave with a peak overpressure of 10 psi and a duration of 230 msec. Figure from Reference 12.)



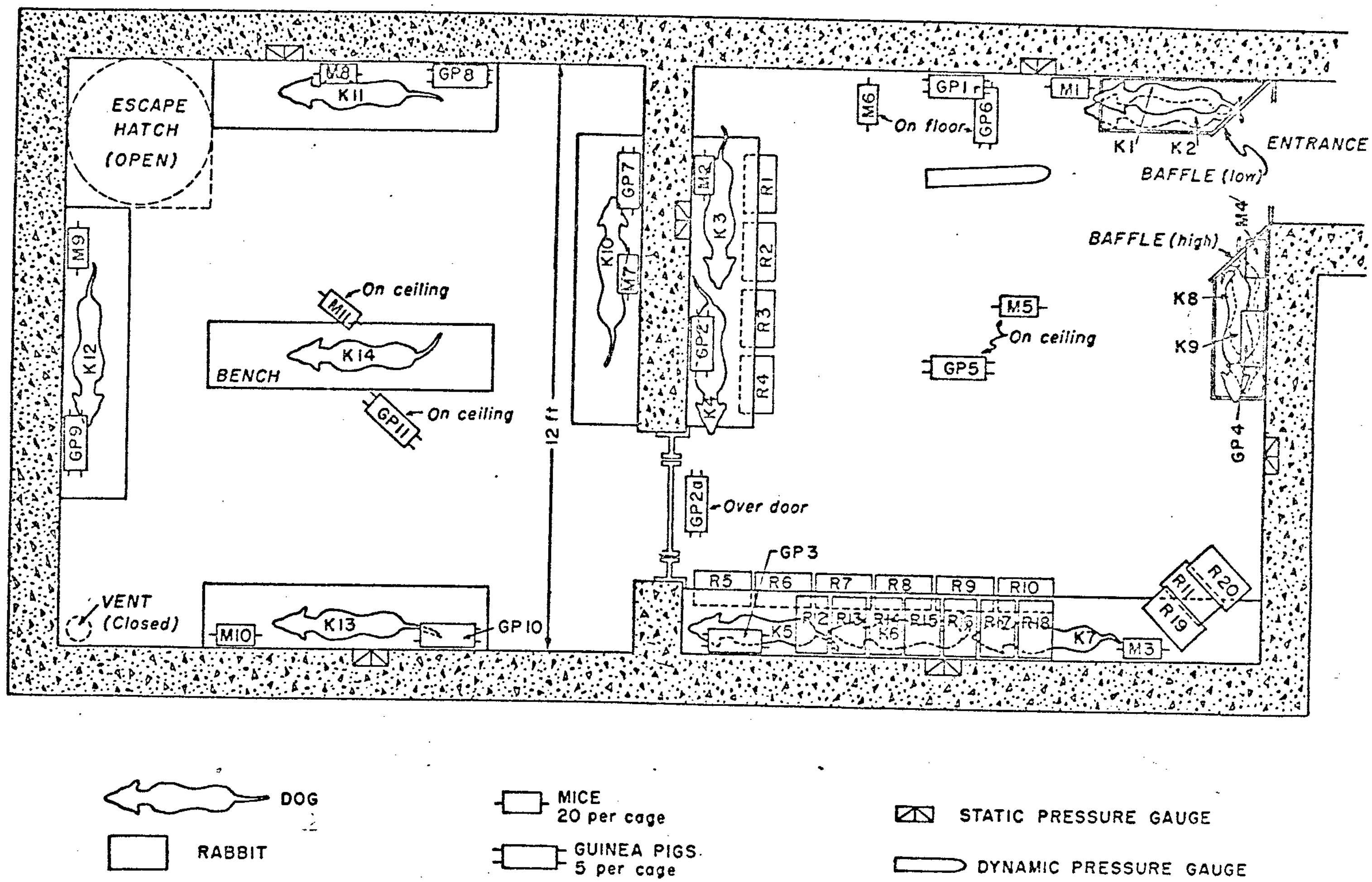
Initial velocity ($\dot{Z}_o$) vs. displacement (S) for animals as a function of mass (m). Computed stopping times (t) are also indicated. Dashed lines are drawn one standard error of estimate from the regression line. (Figure from Reference 12.)



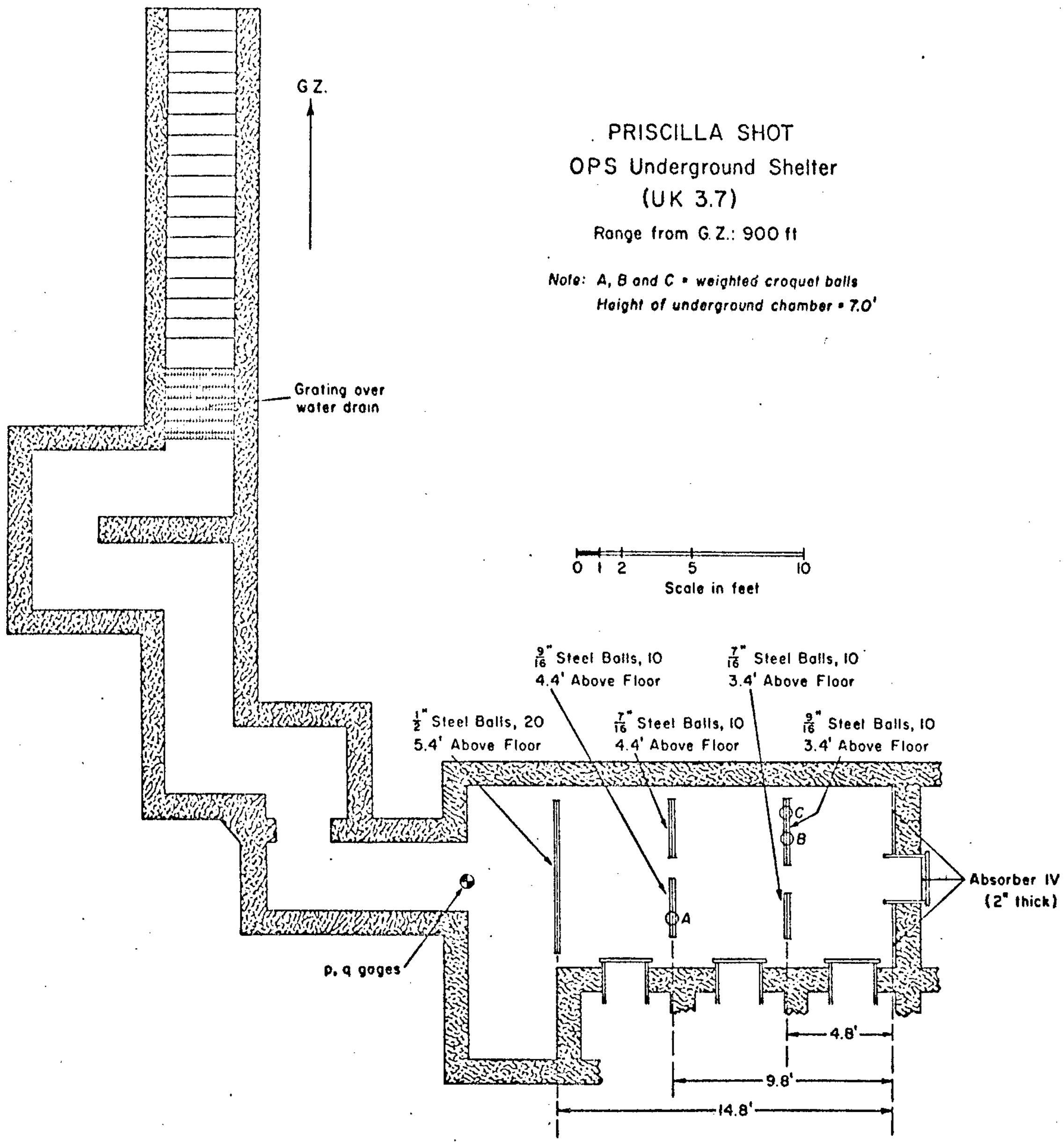
(Comparison of Measured and Predicted Displacements of Dummies Exposed to a 500-Ton HE Surface Burst. Figure from Reference 15.)



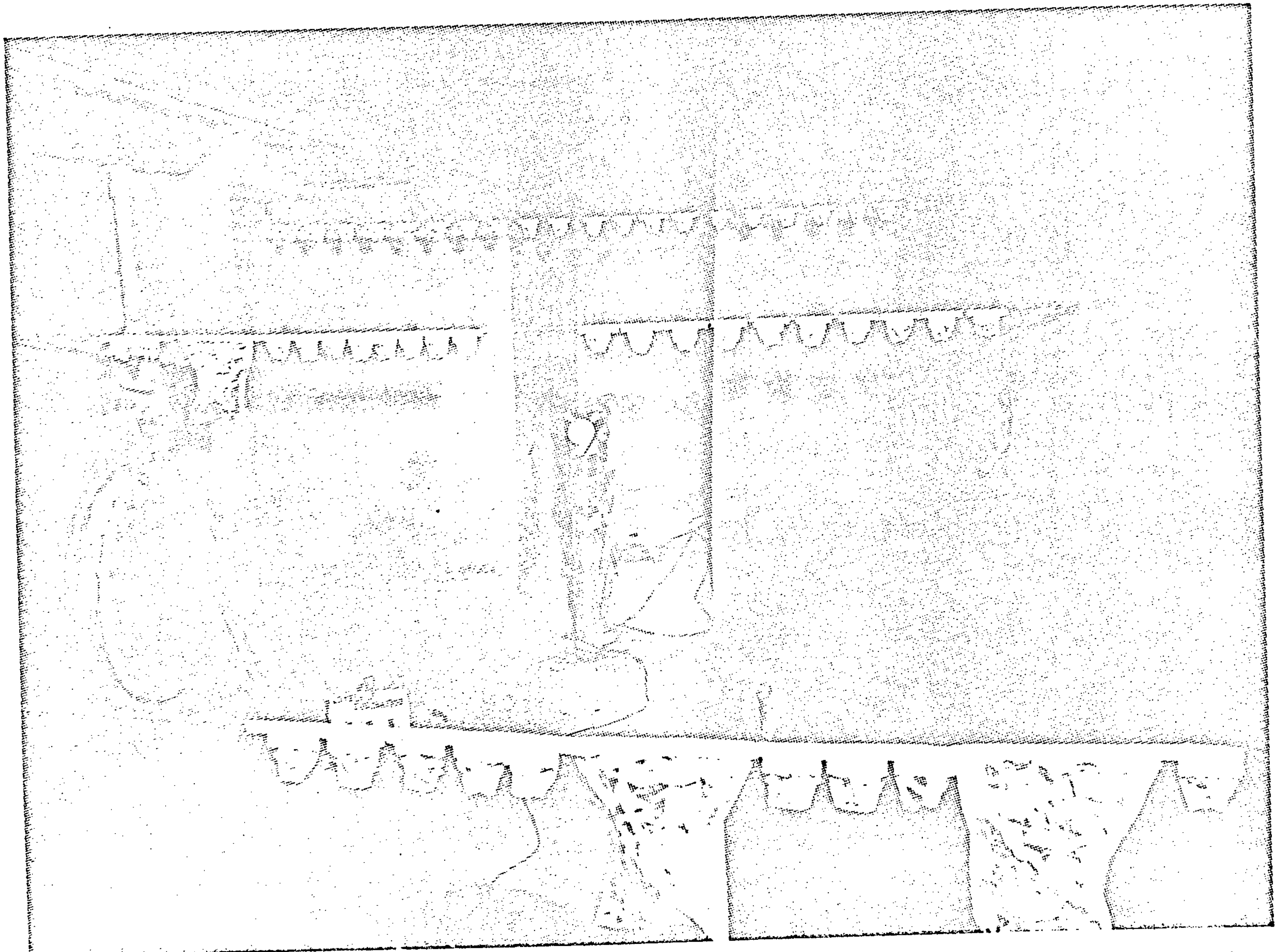
Maximum Velocities Attained by Rats in Scale-Model Foxholes Subjected to Blasts of 18 psi. (Figure from Reference 24).



(Location of animals and instruments used in a study of the primary and tertiary effects of blast in open underground protective shelters. Figure from Reference 20.)

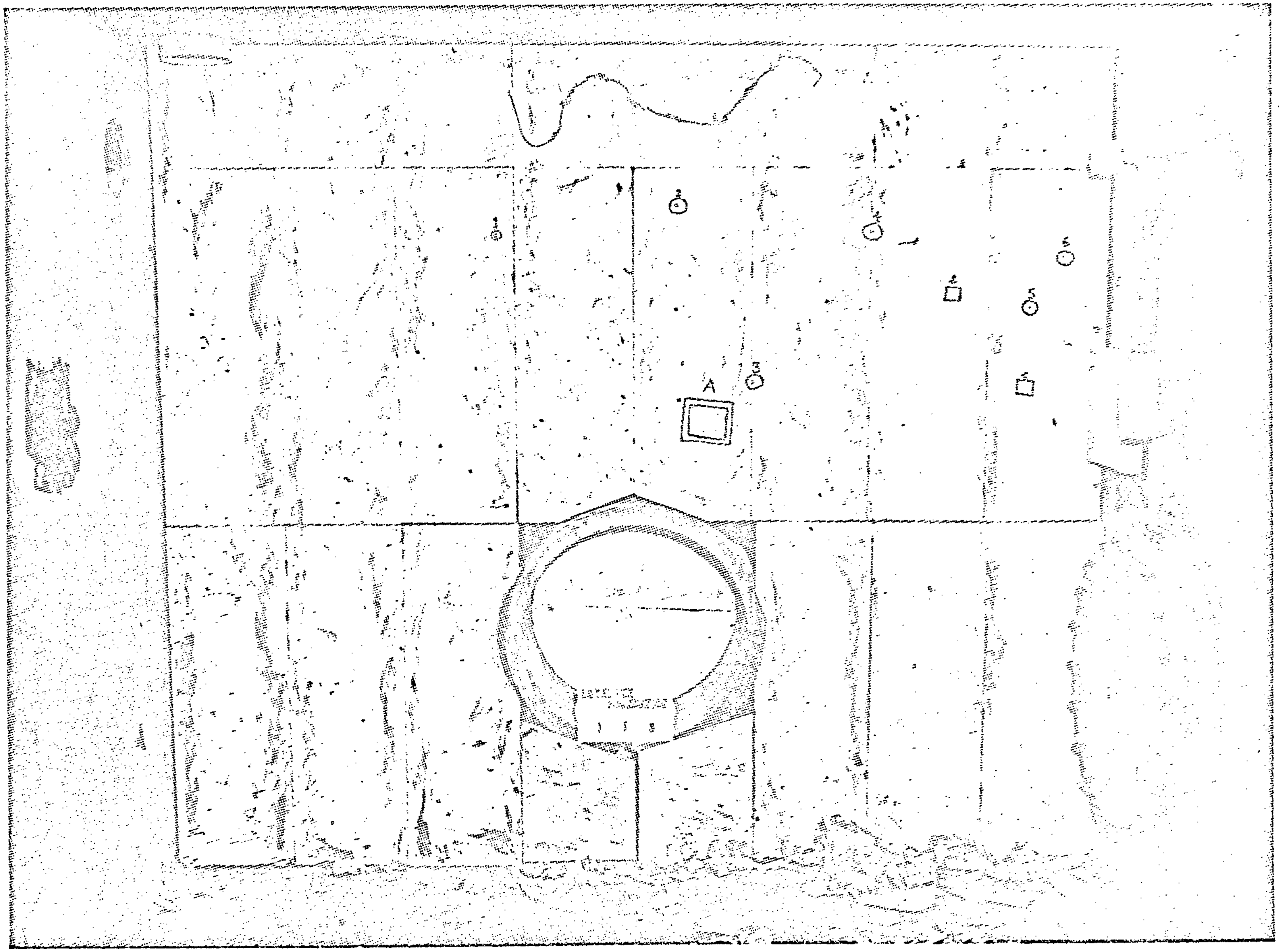


(Plan view of UK 3.7 open shelter, Priscilla Shot, 37 kt, 700-ft HOB, 900 ft from ground zero, peak outside overpressure about 65 psi. Figure from Reference 11.)



Preshot view in the underground shelter, showing steel spheres and three croquet balls in foil bags. The phogotraph was taken near the absorbing material looking toward the entrance. (Figure from Reference 11.)

Postshot view of the absorbing wall in the underground shelter.
(Figure from Reference 11.)



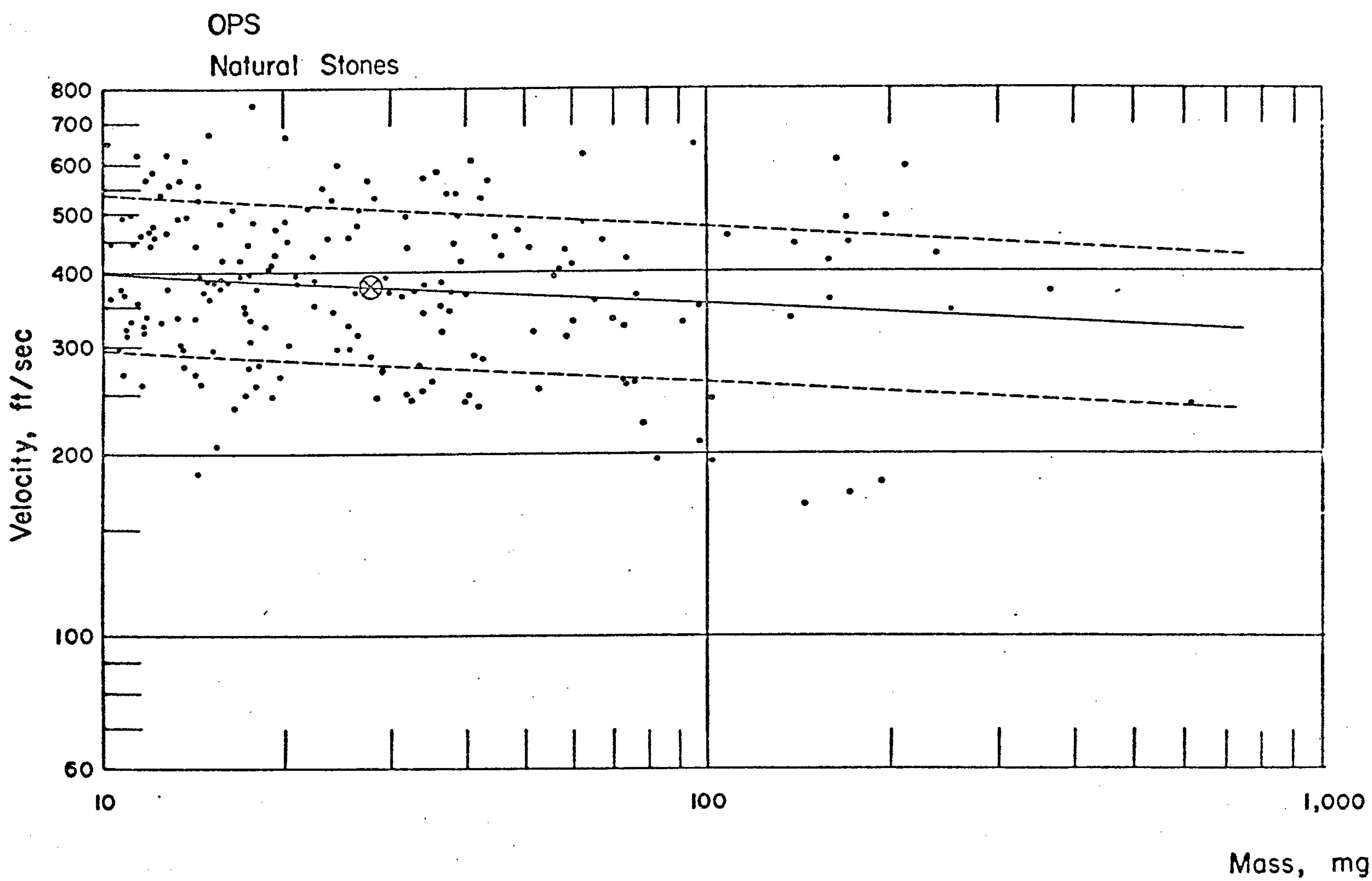
Postshot view of the missile-absorbing material in the underground shelter. The foil had been removed and the impact locations of the spheres marked. (Figure from Reference 11.)

SUMMARY OF TRANSLATIONAL DATA FOR SPHERES EXPOSED IN UK-3.7 SHELTER[21]

SPHERE TYPE AND DIAMETER	ACCELERATION COEFFICIENT (α) FT^2/LB*	DISTANCE TO ABSORBER, FT	NO. MISSILES ANALYZED	VELOCITY FT/SEC					
				AVERAGE		MINIMUM		MAXIMUM	
				FT/SEC	MPH	FT/SEC	MPH	FT/SEC	MPH
1/2" STEEL	0.0348	14.8	6	129	88.0	99.1	67.6	159	108
9/16" STEEL	0.0310	9.8	2	52.9	36.1	52.6	35.9	53.2	36.3
CROQUET BALL	0.0350	9.8	1	45.0	30.7	--		--	

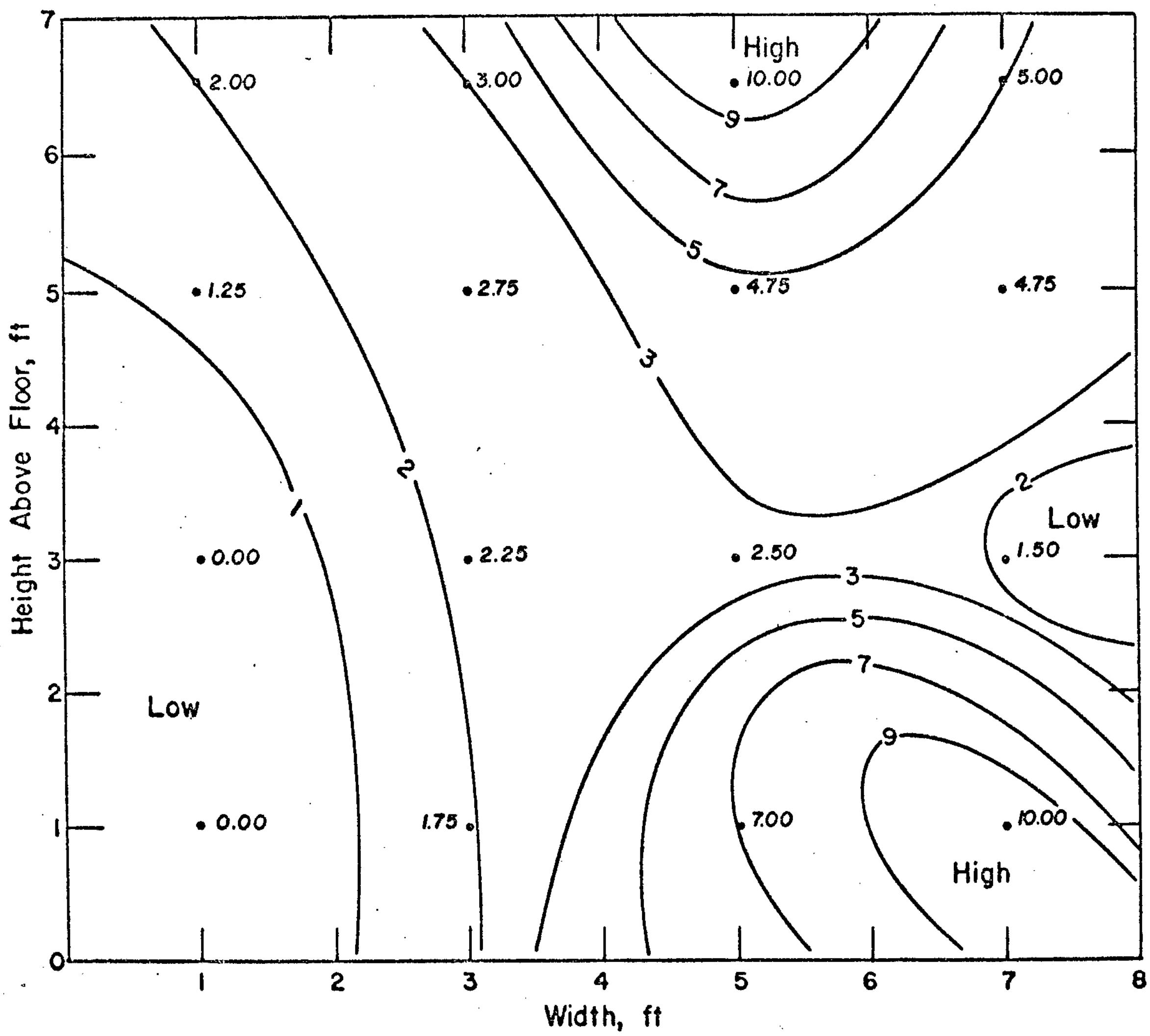
*THE ACCELERATION COEFFICIENT, $\alpha = A/M \cdot C_D$
A= AREA; M = MASS; C_D = DRAG COEFFICIENT.

(Data from Reference 5.)



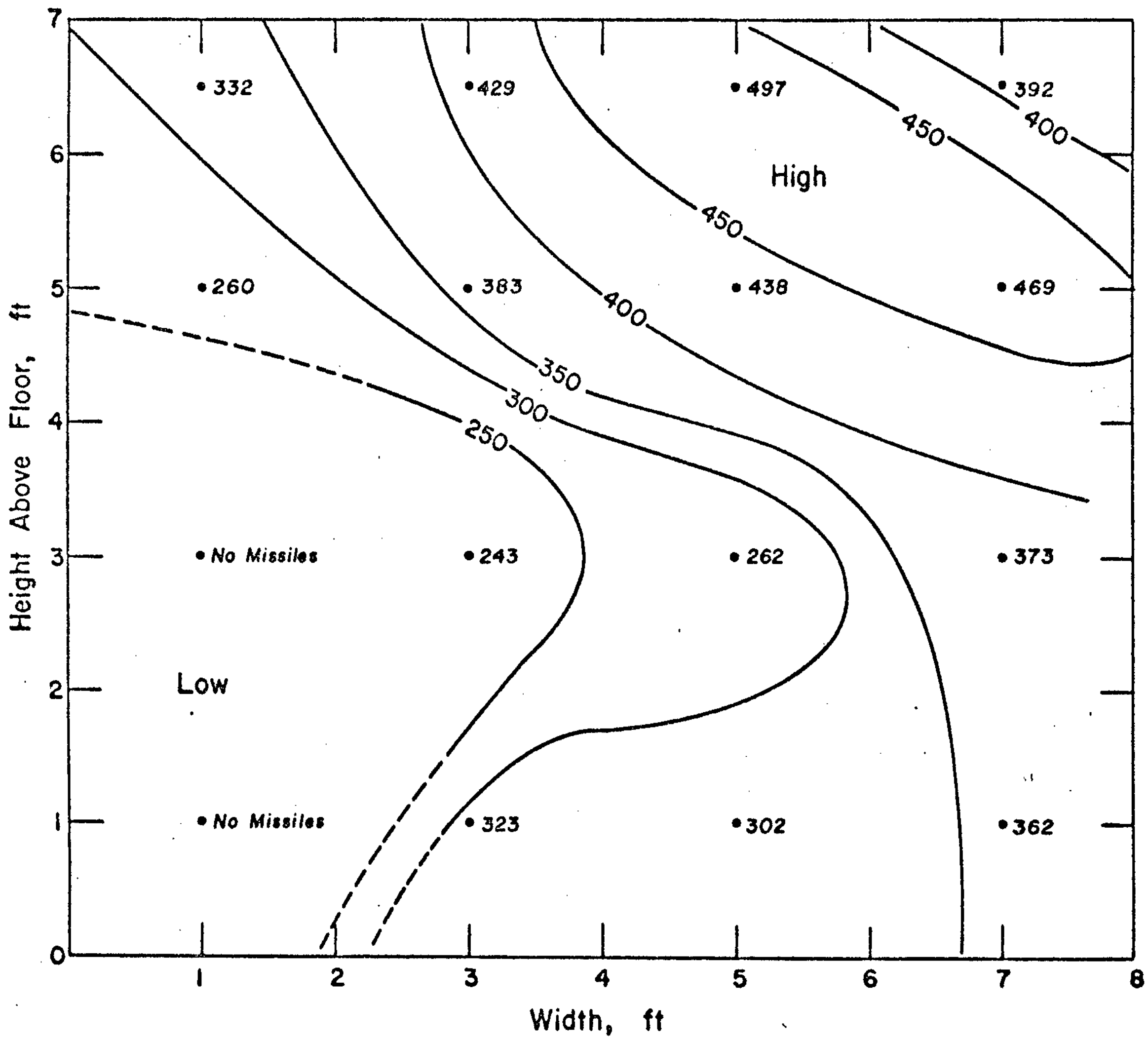
A plot of velocity vs. mass for 194 natural-stone missiles caught by the absorber in the underground shelter. (Figure from Reference 11.)

NATURAL STONE SPATIAL DISTRIBUTION, OPS



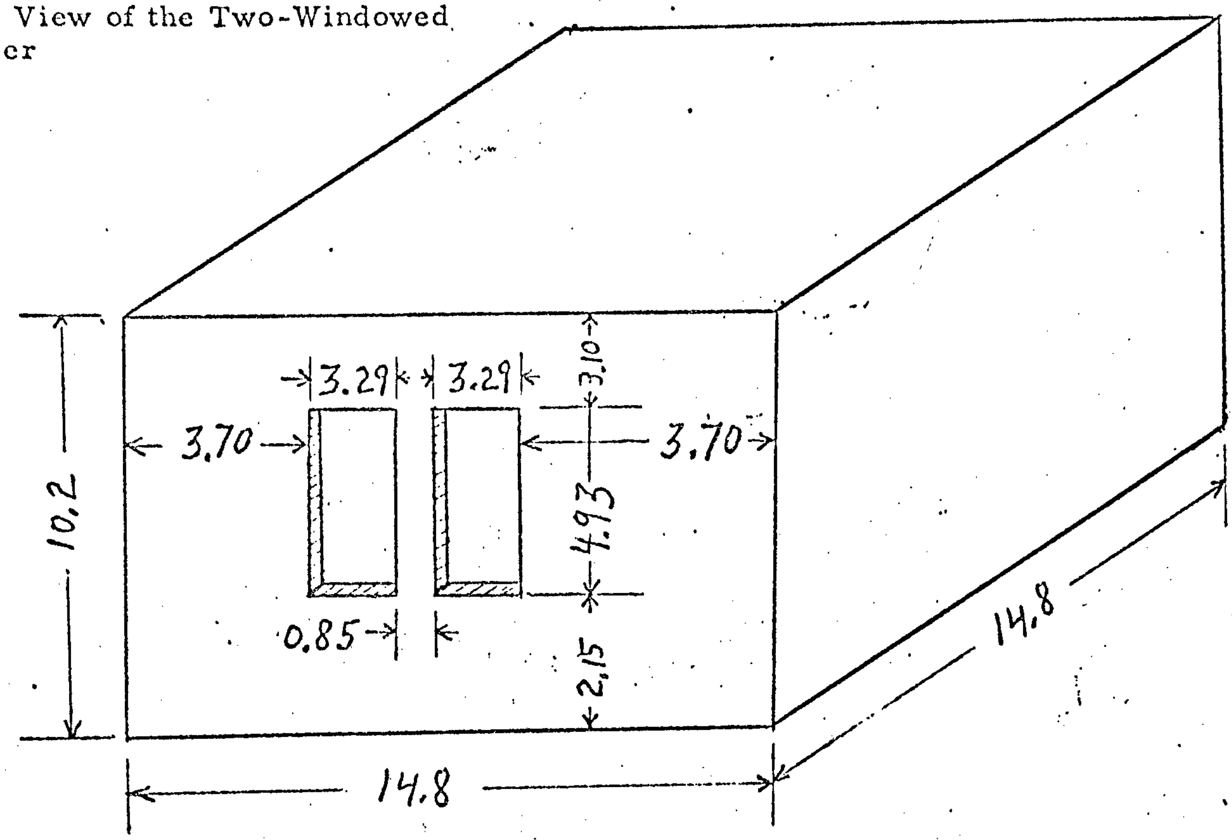
Spatial distribution of natural-stone missiles recovered from the underground shelter. Numbers indicate missiles per square foot. (Figure from Reference 11.)

NATURAL STONE VELOCITIES, OPS

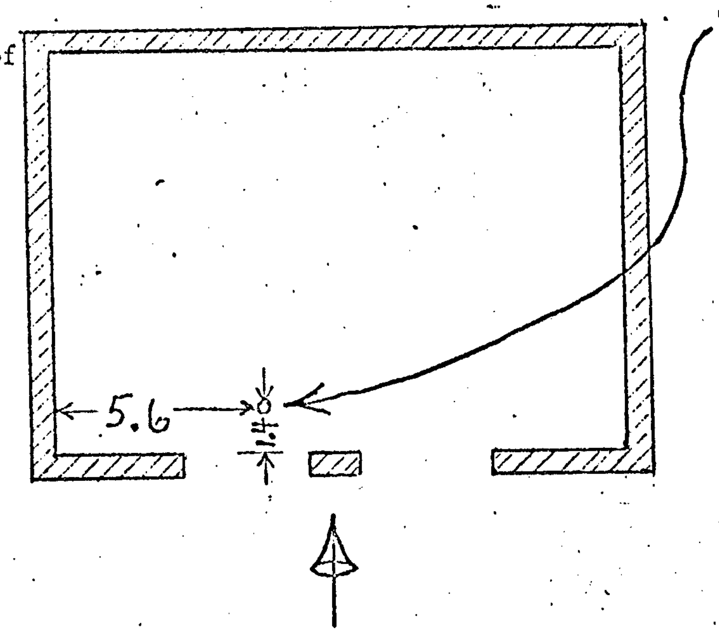


Spatial distribution of the average velocities (in ft/sec) of natural-stone missiles recovered from the underground shelter. (Figure from Reference 11.)

Isometric View of the Two-Windowed Chamber



Overhead View of the Lower Half of the Chamber



The Translation Data Apply to a Man Initially Standing Upright at this Position

Direction of Propogation of the Incident Shock Wave

$$\frac{\text{volume}}{\text{area}} = \frac{10.2 \times 14.8 \times 14.8}{2 \times [4.93 \times 3.29]} = 69 \text{ ft.}$$

Note: All dimensions are in feet and apply to a 70 kg man in the full-scale situation. The dimensions and times were scaled from experiments with 0.53 kg monkeys; scaling factor $(70 \text{ kg}/0.53 \text{ kg})^{1/3} = 5.1$

(Figure from Reference 16.)

DATA OBTAINED WITH MONKEYS IN THE TWO-WINDOWED CHAMBER

Shot number and date	Peak[a] incident over-pressure, psi	Peak[a,b] reflected over-pressure, psi	Duration[a,c] of positive incident overpressure, msec	Chamber[c,e] fill time, msec	Peak[d] velocity of glass, ft/sec	Displacement[c] of glass to peak velocity, ft	Impact[d] velocity of monkey, ft/sec
S-4 21 Jan 69	4	9	260	74	190	2-3	37
S-2 27 Jan 69	6	14	320	67	220	1-2	51
S-3 27 Jan 69	10	26	410	76	290	1-2	81
				72 avg.			

[a]This measurement was made on the outside of the chamber.

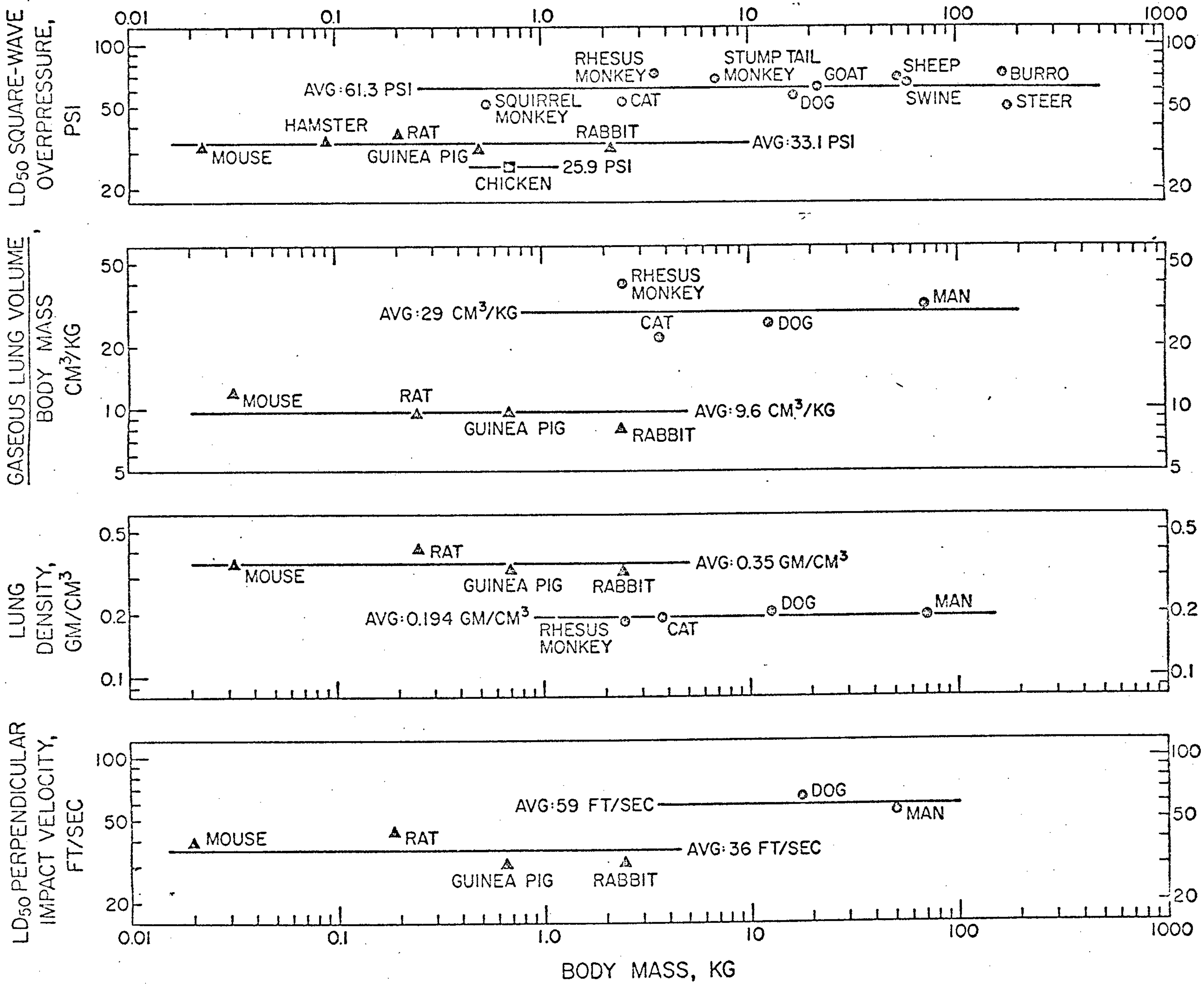
[b]By considering this to be the incident rather than the reflected pressure, the given velocities, times, and distances may be assumed to apply to situations where the blast wave does not reflect at near-normal incidence.

[c]The measured value has been multiplied by 5.1; it therefore applies to a man in the full-scale situation.

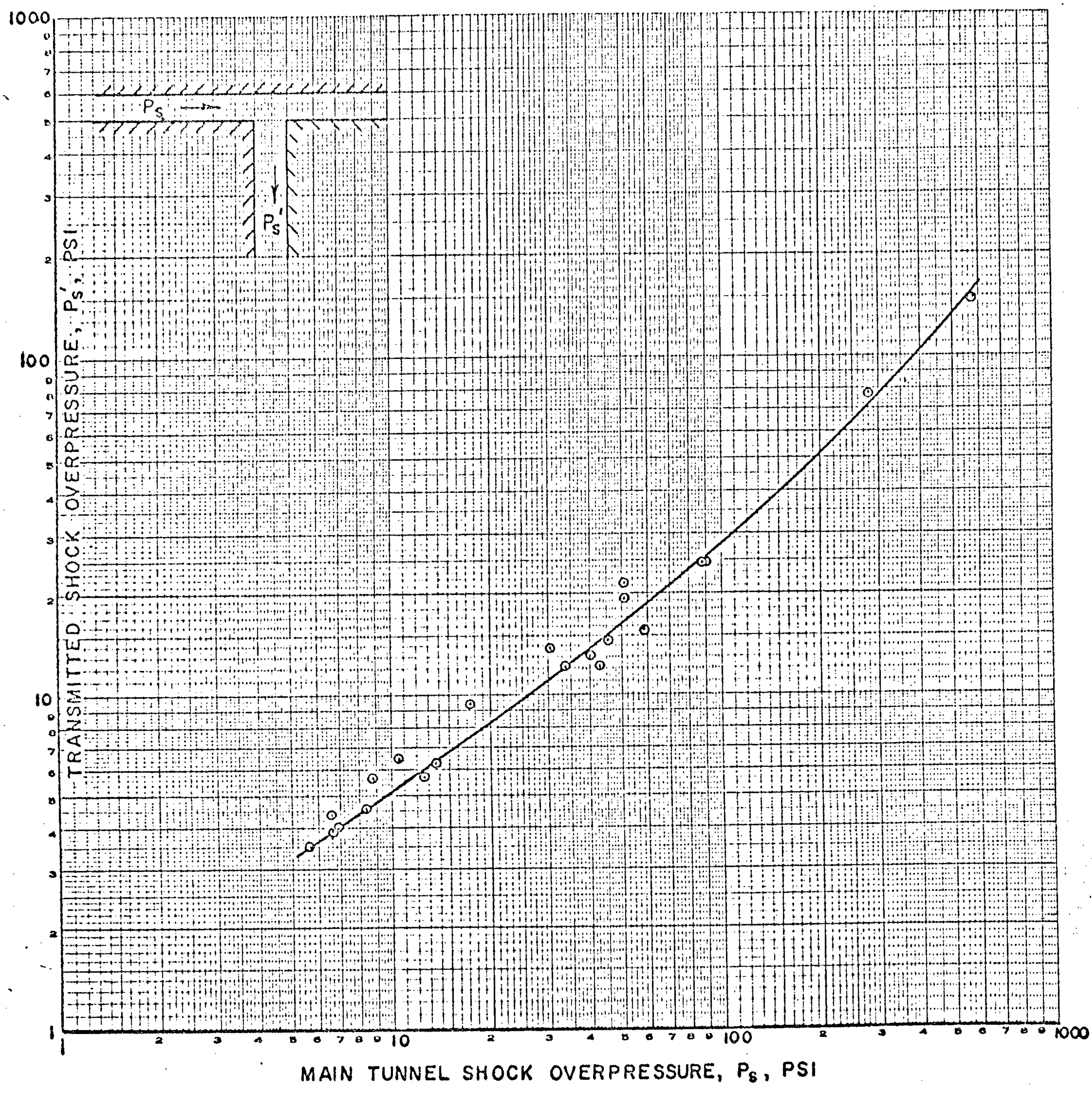
[d]The peak translational velocity is approximately equal to the impact velocity.

[e]This is the time to peak pressure inside the chamber. It is approximately equal to the time to peak translational velocity for a man.

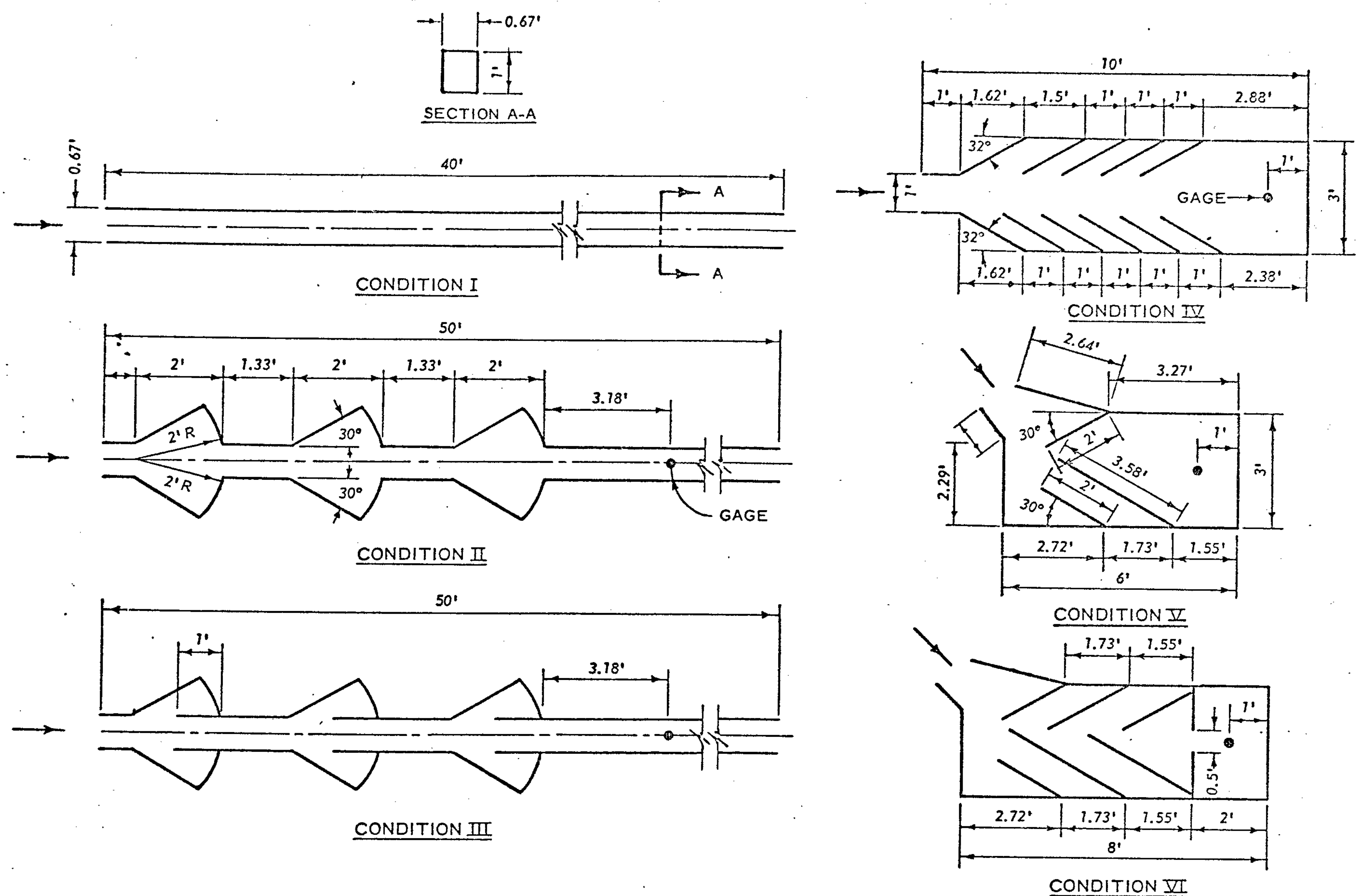
(Table from Reference 16.)



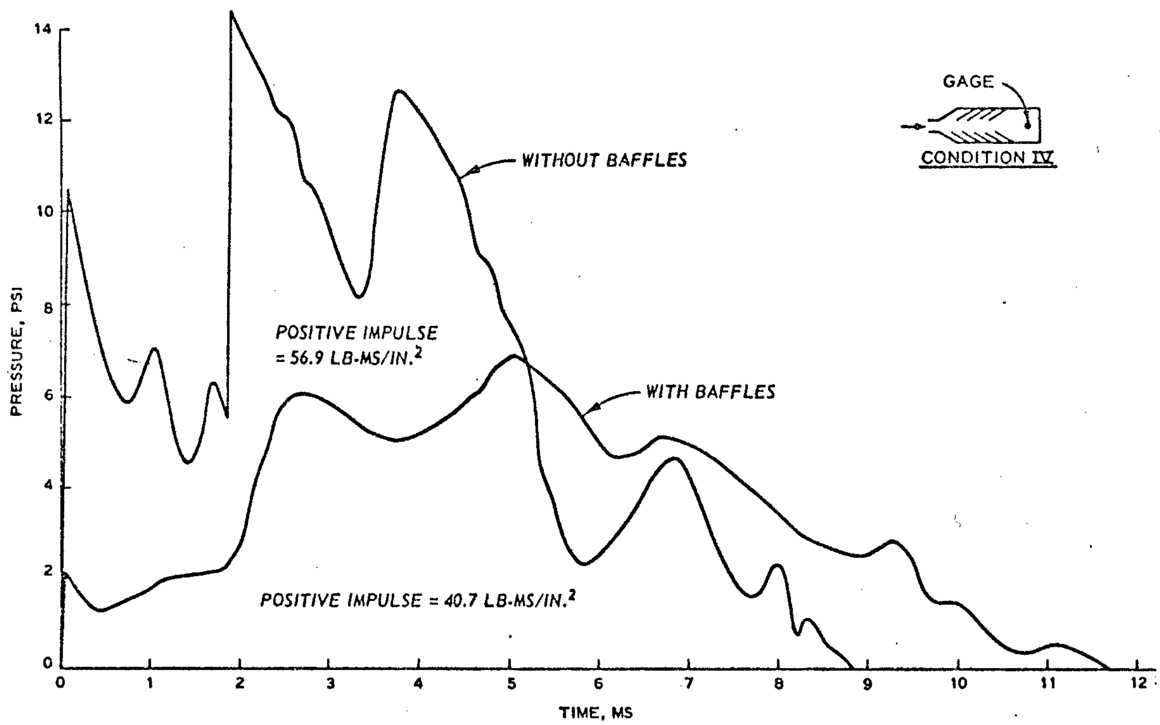
Animal body mass vs (1) LD_{50} square-wave overpressure for $P_0 = 14.7$ psi, (2) average gaseous lung volume divided by animal body mass, (3) average lung density, and (4) LD_{50} velocity for perpendicular impact with a non-yielding surface. Note that in each case the mammals are divided into two groups. Average values of the various parameters are indicated for both groups. (Figure from Reference 14.)



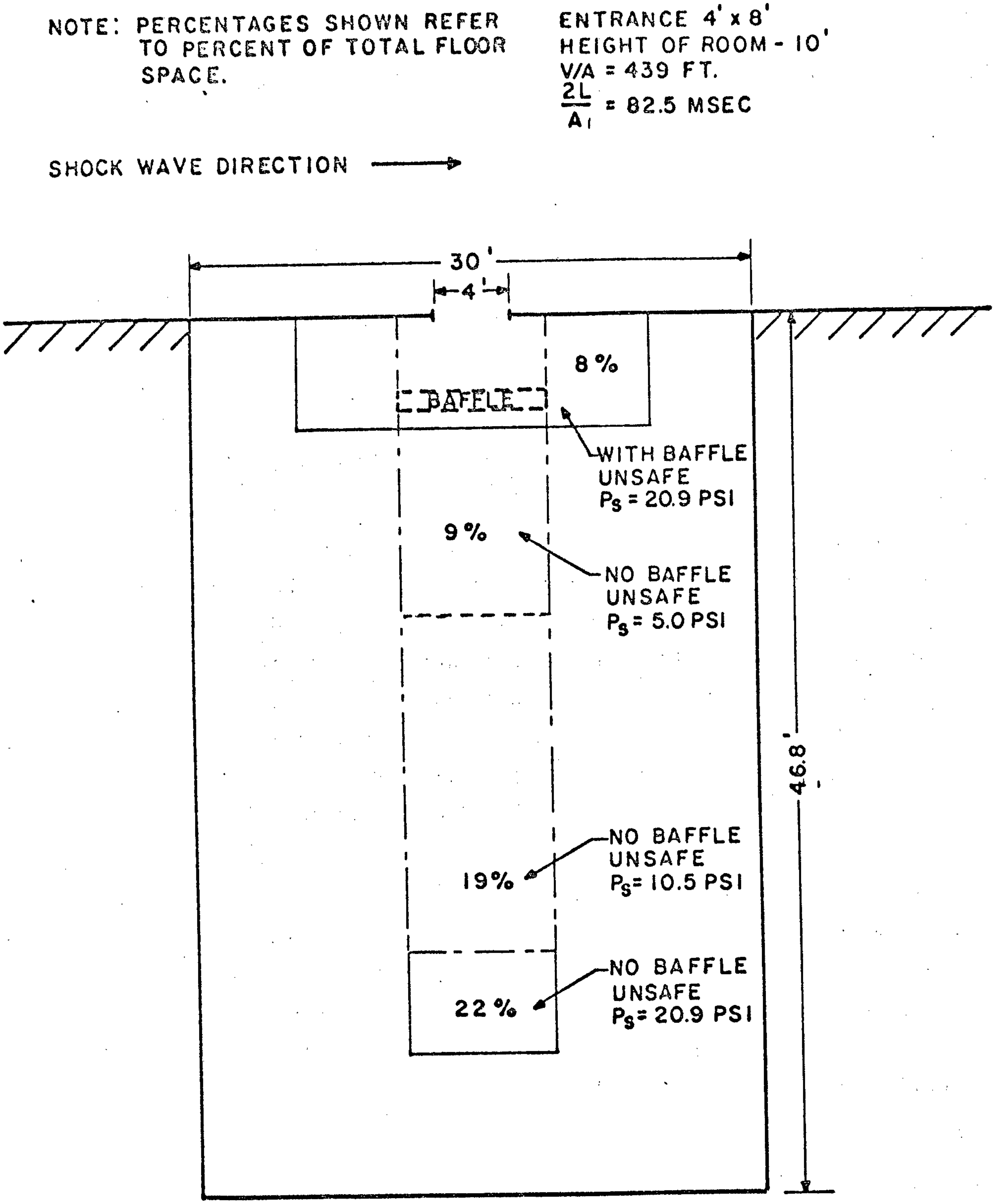
INCIDENT vs. TRANSMITTED SHOCK OVERPRESSURE FOR TUNNEL JOINED TO AN EQUAL AREA TUNNEL (Figure from Reference 1.)



Plan of test structures
(Figure from Reference 2.)

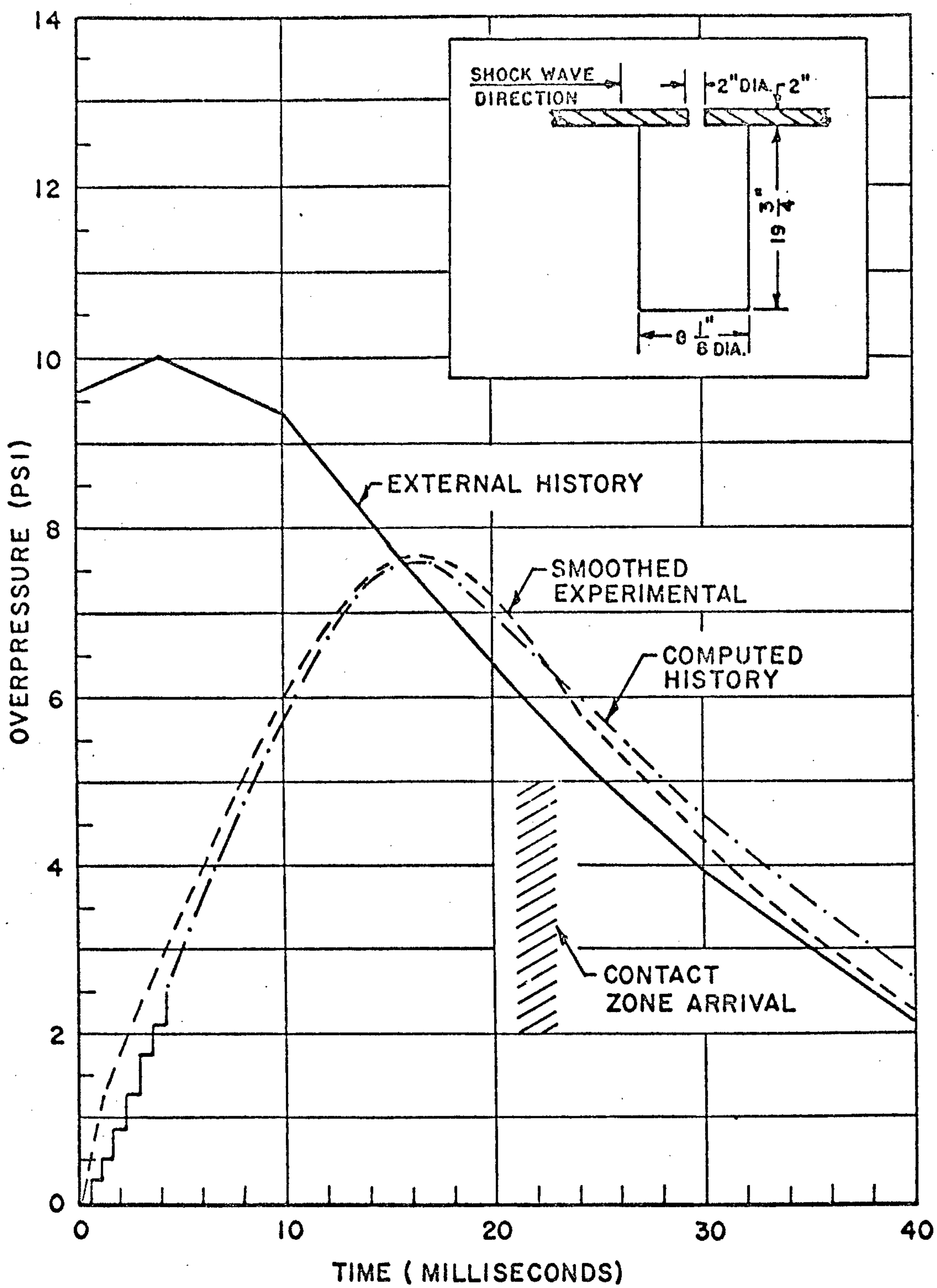


Condition IV wave form
(Figure from Reference 2.)

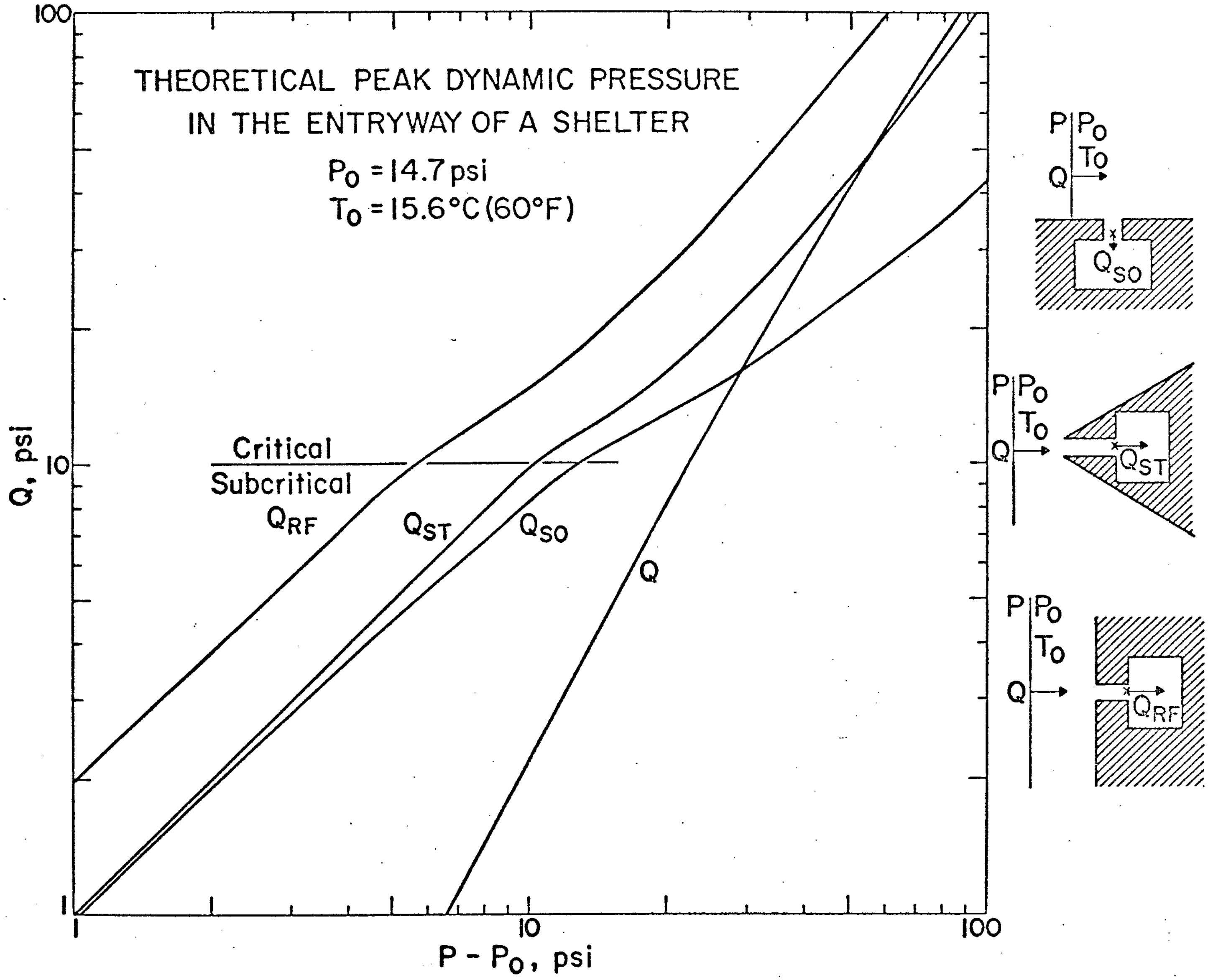


Full-Size Room for Model 25-A

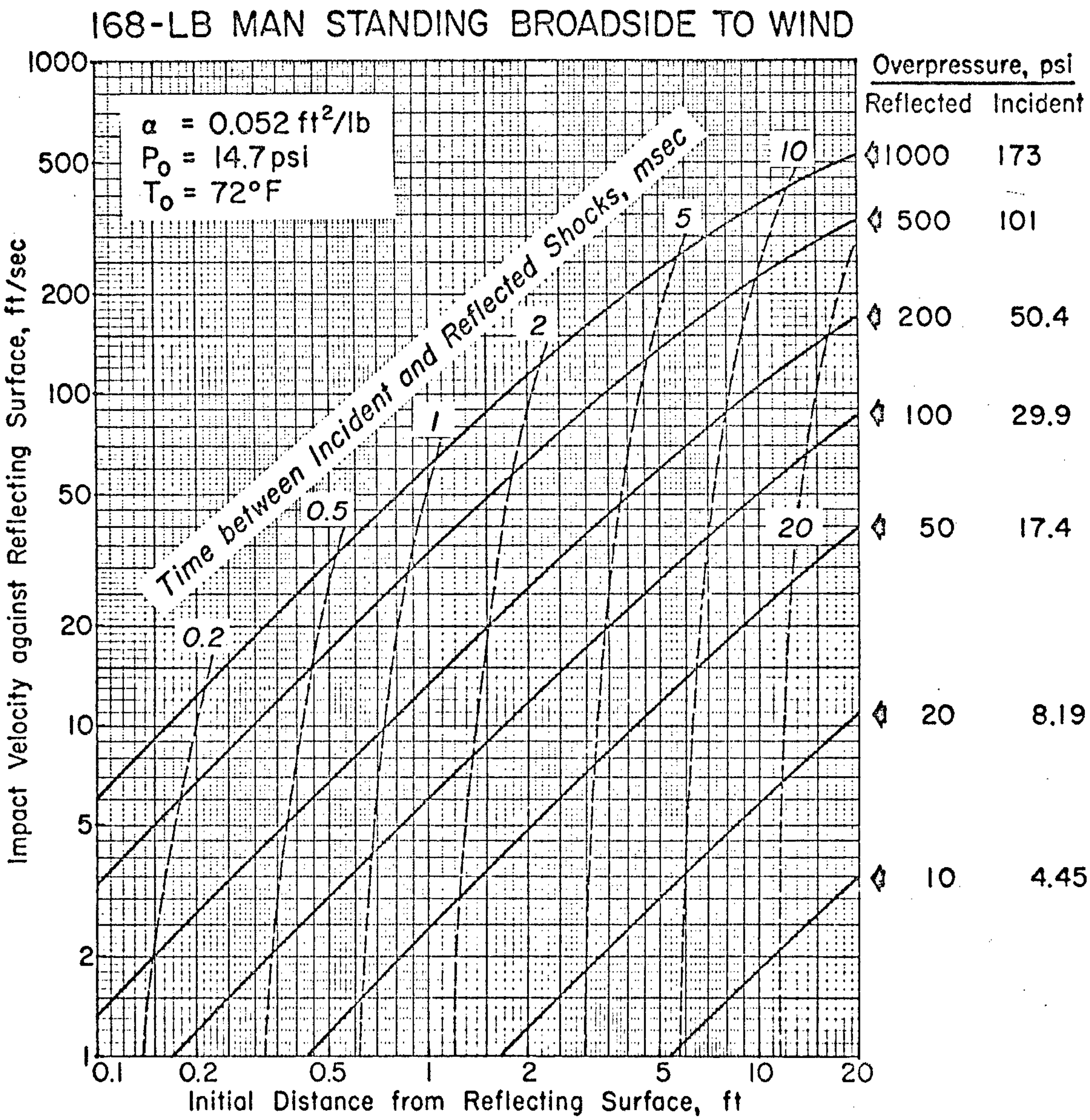
(Figure from Reference 7.)



Fill history for side-on incidence
(Figure from Reference 19.)



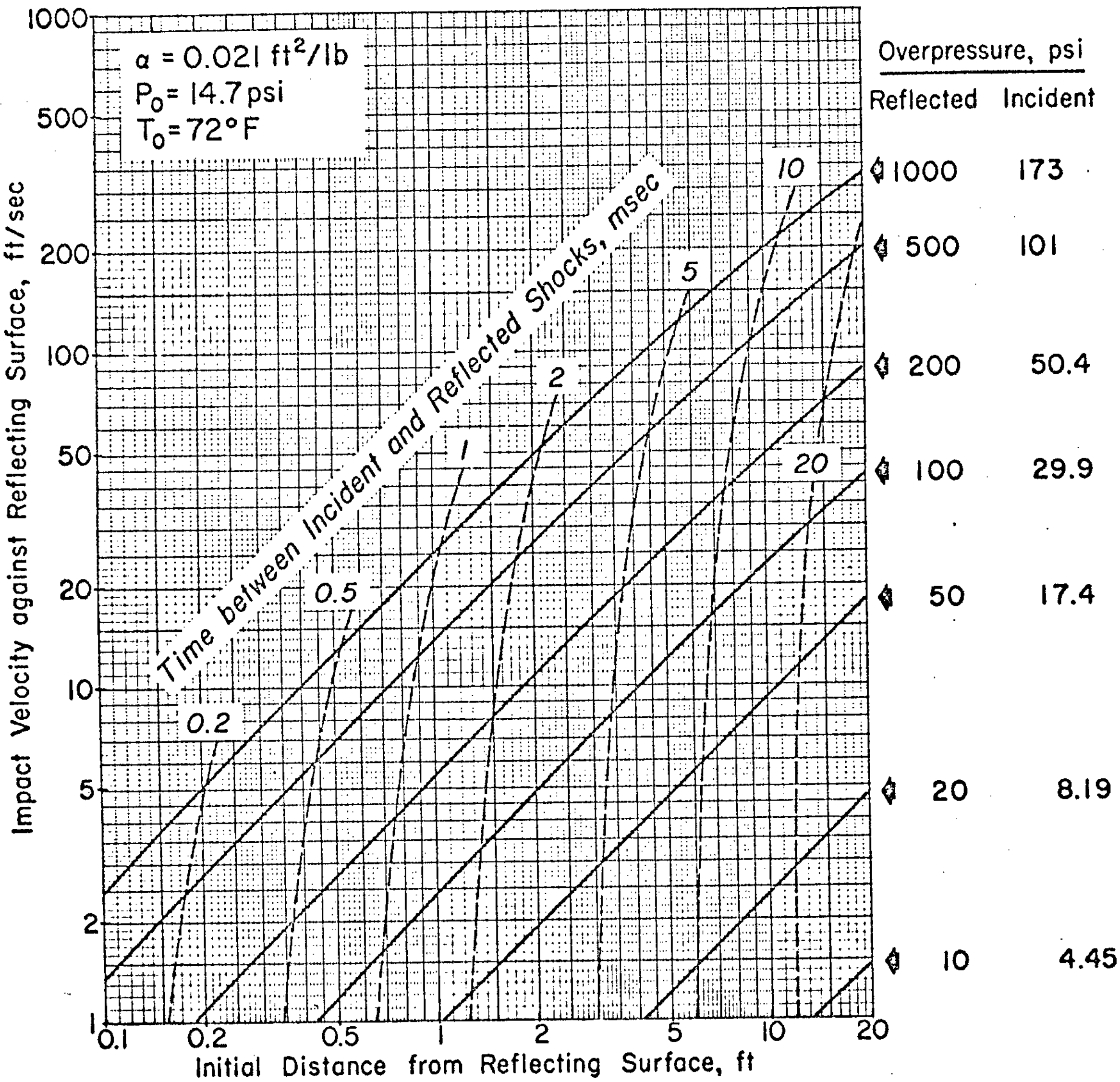
Theoretical peak dynamic pressure in the entryway of shelters with various geometries and orientations with respect to a blast wave. (Figure from Reference 11.)



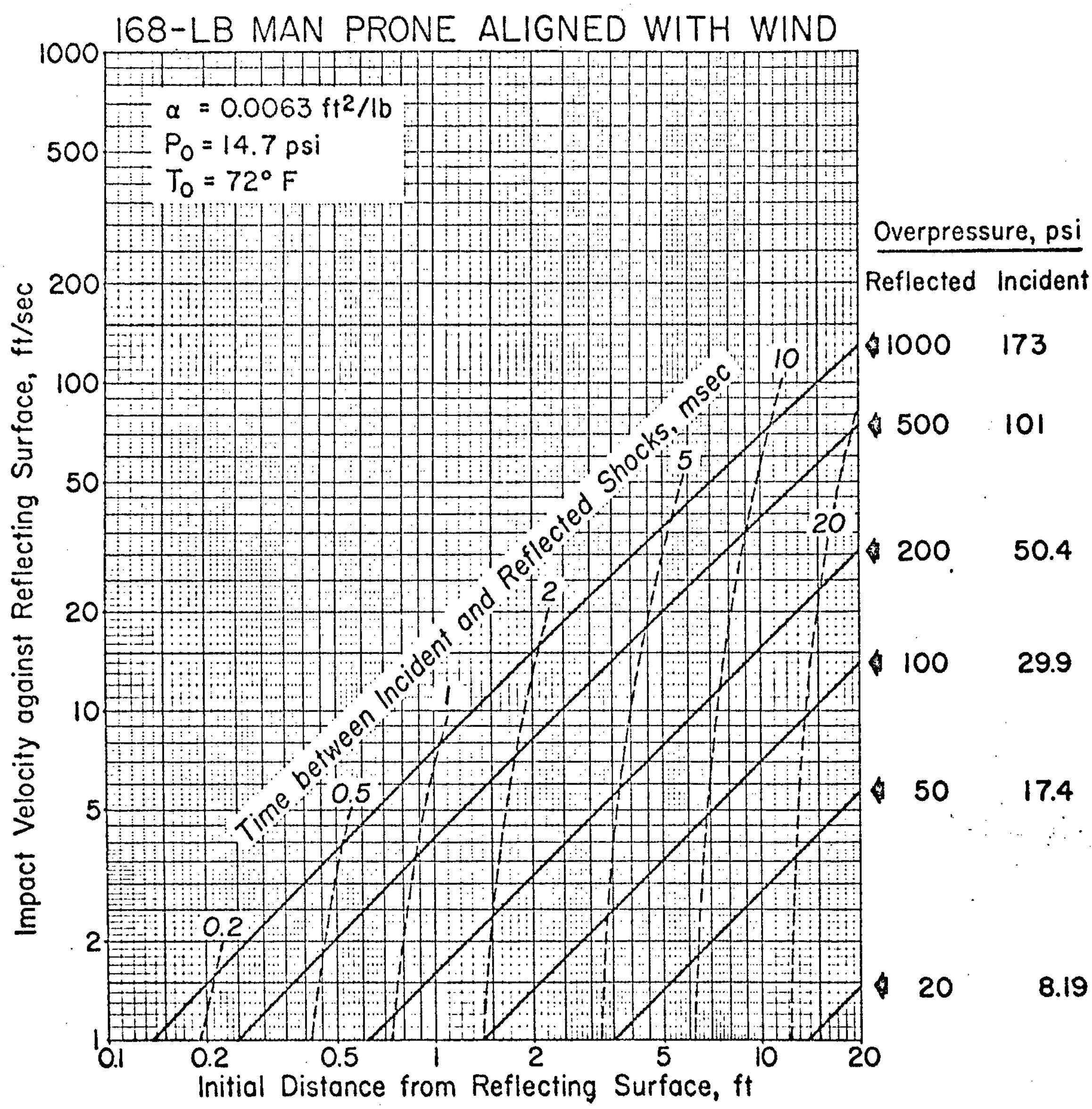
Computed impact velocity of a man standing broadside ($a = 0.052$ ft^3/lb) to the winds associated with a square wave, as a function of overpressure and the initial distance of the man from the vertical surface reflecting the blast wave at normal incidence.

(Figure from Reference 11.)

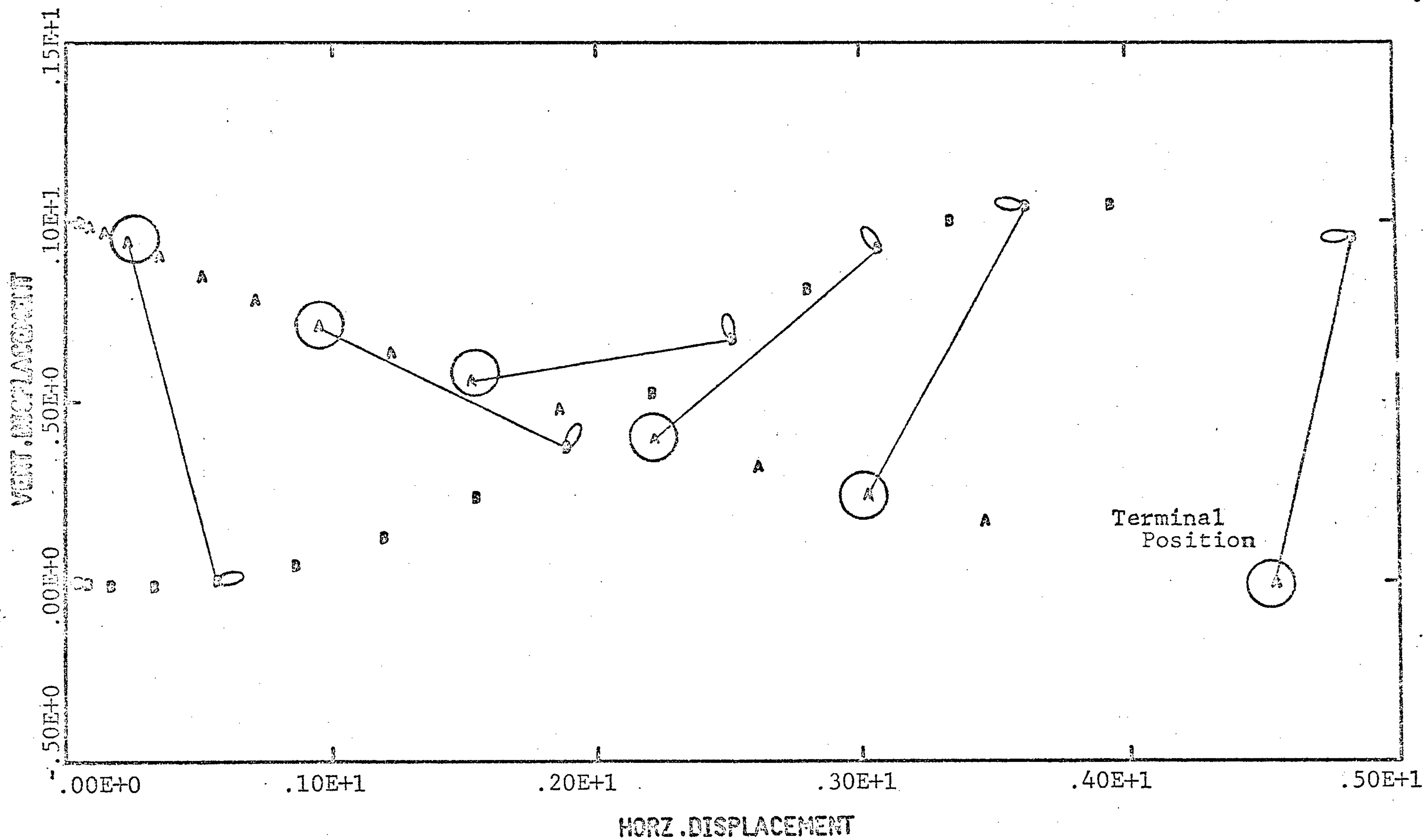
168-LB MAN CROUCHING BROADSIDE, STANDING SIDEWISE, OR PRONE PERPENDICULAR TO WIND



Impact velocity of a man crouching broadside, standing sidewise, or prone perpendicular ($a = 0.021$ ft^2/lb) to the winds associated with a square wave, as a function of overpressure and the initial distance of the man from the vertical surface reflecting the blast wave at normal incidence. (Figure from Reference 11.)



Impact velocity of a man prone aligned (a = 0.0063 ft^2/lb) with the winds associated with a square wave, as a function of overpressure and the initial distance of the man from the vertical surface reflecting the blast wave at normal incidence. (Figure from Reference 11.)



(Calculated motion of a man initially standing back-on to the entrance midway into an 80-ft-long shelter exposed to a 30 psi overpressure. Figure from Reference 26.)

Computed flow past a rectangular rod showing the development of the Von Kármán Vortex Street, after Harlow and Fromm. (Figure from Reference 17.)

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